BRAIN

A JOURNAL OF NEUROLOGY

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Brain

A Journal of Neurology

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March, 1953

BRAIN

VOL. 76, PART 1.

THOUGHTS UPON THE EQUATION OF MIND WITH BRAIN[1]

BY

F. M. R. WALSHE

Introduction

Among the many aspects of Jackson's thought and work that have provided themes for earlier lecturers in this series, I do not recall that his conclusions upon the relation of mental to nervous activities, that is upon what is now commonly spoken of as the mind-brain relationship, have ever been chosen.

Of the many possible reasons for this, and there are cogent ones, it may well be that by the time the invitation to give this lecture reaches him, the neurologist has acquired discretion and remembers that there are places where angels fear to tread.

Moreover, in our own day, the subject seems to exercise its greatest attraction for, and to have been given a forbidding colour by, philosophers of anti-intellectualist schools, and by biophysicists of the Cybernetic persuasion, whose confident conclusions as to the nonentity of mind would be more acceptable were we able to feel they were rooted in a sounder philosophic tradition, or informed by a more adequate insight into men and minds in the particular. The physician, therefore, tends in general to shrink from it.

Thus I take up this theme with modest expectations, my eyes open to its dangers, but consoled by the hope that you will not expect me to treat it in any orthodox fashion, nor to invest what I have to say with a portentousness beyond its weight.

Jackson's view, which, though my starting place is not my terminus of thought, is stated by him clearly in short passages scattered through many of his papers, particularly in those dealing with the evolution and dissolution of function in the nervous system.

[1] The 13th Hughlings Jackson Lecture, delivered before the Royal Society of Medicine, London, December 4, 1952.

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A few quotations will suffice to show where he stood in this matter. He says: "We cannot understand how any conceivable arrangement of any sort of matter can give mental states of any kind." (H.J.i.52)[1] "Psychical states are never states of the organism" (H.J.ii.95).

"The very simple affirmation is that consciousness attends activity of certain nervous arrangements, and ceases when these nervous arrangements are *hors de combat* . . . What the nature of the relation is nobody knows" (H.J.ii.16).

Again, "The evolutionist can take a brutally materialistic view of disease of any part of the nervous system, for the reason that he does not take a materialistic view of mind: does not confound psychical states with nervous states. . . . The doctrine of evolution has nothing to do with the nature of the relation of psychical to physical states of the highest nervous centres: it simply affirms concomitance of psychical states with states of these centres" (H.J.ii.41).

Finally, he commits himself explicitly to the doctrine of psychoneural concomitance, adding that "I am not competent to discuss the metaphysical question of the relation of mind to nervous activities" (H.J.ii.84).

Now this conclusion is not quite the simple negative it may at first sight appear to be, nor is it, perhaps, a strict doctrine of psychoneural concomitance. He does not say with Descartes that "the mind is a separate substance requiring nothing but itself in order to exist," for he allows that psychical states require the concomitant activity of nervous states and do not obtain without these, while, on the other hand, some nervous activities at least neither require nor have concomitant psychical states. That is, the relation between the two is not a symmetrical one.

Further, his explicit disavowal of the common assumption that the human mind, like the body, is the product of evolution, can only mean that he adopts some form of animism, and, by implication, accepts a spiritual element in man. Why else, indeed, should he say that the mind-brain relationship is a metaphysical problem? For in so saying he passes beyond the realm of proximate causes with which alone does natural science deal.

I think that for a man with no source of philosophical guidance or inspiration other than his own Victorian age so very meagrely provided, and surely there has been no more arid chapter in the history of English philosophy than this, there is something we must respect in this austere confession of ignorance, this determination to abide by his conception of the nervous system as something to be thought of only in terms of

[1] These references are to volume and page of "The Selected Writings of John Hughlings Jackson," 1931, 1932.

physiology, relieved by the implicit admission that there is a metaphysical problem involved in the relationship of mind to brain.

One has only to read the opening chapter of Karl Pearson's "Grammar of Science," with its confident and uncomprehending attack upon metaphysics, to appreciate the courage needed by any man of science of the late nineteenth century who ventured to invoke metaphysics in respect of a problem science failed to illuminate for him. The very word was anathema.

We cannot pass from this standpoint of Jackson's without brief reference to the somewhat comparable viewpoint of that other great master of our own yesterday, Charles Sherrington, as revealed in his Rede Lecture and in the final chapter of his Gifford lectures, which is entitled "Two ways of one Mind."

For Sherrington there were two concepts, that of organism and that of mind. An organism with recognizable mind was for him "a space-time system which the energy concept because of that mind fails to cover fully." These two concepts are complemental, each without the other is incomplete, and we have to treat them as having contact and concomitance. He adds that "if the mind-concept is so applied as to insert into the human individual an immortal soul, a trespass is committed, which on the plane of Natural Knowledge is an irrational blow at the solidarity of the individual."

Similarly, the Lucretian view of mind as composed of little bits of matter was a comparable trespass.

Finally, he says that mind and the perceived world are two separate and incommensurable concepts, both parts of the knowledge of one mind: "We are the tie between them."

I confess myself unable to understand the nature of the "we" which binds these two separate and incommensurable concepts, or, how, thus imagined, these can confer solidarity upon the individual—whether, indeed, "individual" is a proper term to apply to an entity thus incomprehensibly constituted.

It is difficult to believe that Sherrington himself was happy in this conclusion, for in a further passage he says, "Mind, for anything that perception can compass, goes therefore in our spatial world more ghostly than a ghost. Invisible, intangible . . . it remains without sensual confirmation and remains without it for ever. Stripped to nakedness there remains to it but itself. What then," he asks, "does that amount to? All that counts in life. Desire, zest, truth, love, knowledge, values . . ."

Yet are not these the forces that inspire and direct our bodily activities? Are they truly more ghostly than a ghost in man's life? Can a pale

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concept of psychoneural concomitance embrace this situation which is the delivery of experience for all of us?

I am convinced that Sherrington, who was both poet and humanist, did not really think so. He may well have thought these things outside the pale of natural science, and what is this but thinking that there are other valid universes of discourse about man than natural science provides, even though he was not willing to enter them?

Now although these great thinkers in our discipline have both gone farther than many scientists today are prepared to go, yet they have in fact halted on the threshold of the problem, and we are left wondering whether, perhaps, out of a deep sense of loyalty to natural science they were not remaining silent as to their deeper intuitions of reality.

A modern philosophical writer, Josef Pieper (1952), has said that "even where natural knowledge is concerned, the discovery of truth is not merely a matter of hard thinking, and when the truth concerns the meaning of the world, a good brain is not enough: the whole human personality is involved." The point is not without relevance to our present discussion, for the natural scientist tends to shrink back in his quest for truth when the possibility dawns on his mind that perhaps after all the ancient concept of the soul is not yet dead, and may once again have to be invoked to account for the activities of the human mind as history, literature and our own experience reveal them.

It is so easy to persuade one's self that truth cannot possibly lie that way. Yet we can scarcely be said to be pursuing truth if we prejudge its nature and restrict its sources in this fashion, and to do so is not an intellectual adventure. It is simply buying a return ticket.

In this disturbing situation, for the scientist's mind no more works in an emotional vacuum than any other man's, there seem two possible ways of escape for him, if, not accepting these dualisms we have described, he is yet unwilling to travel farther.

He may either follow the modern schools of anti-intellectualist philosophy which propose the dialectic destruction of mind as a necessary concept, or, alternatively, he may fall in behind the schools of biophysical speculation which accept the electrical activities of neuronal circuits as adequate to account for all the manifestations of the human mind.

Whitehead's Philosophy of Nature

Before leaving this aspect of our subject it is natural to ask whether amongst modern thinkers of standing there is not at least one who can propose for our consideration some concept of mind that gives it an assured and undisputed place in nature, as a component in the diverse functionings that go to make up nature.

Happily there is something more positive and more in harmony with experience, and we may find it in the writings of Alfred North Whitehead, and for us who are not philosophers by training it is stated most clearly in two lectures entitled "Nature Lifeless" and "Nature Alive" in the small volume, "Modes of Thought."

It is a thousand pities that this volume is out of print at a time when it could provide so precious a corrective to the teachings of those who would have us believe that Man and his nature are inherently reducible to terms of statistical averages and mathematical formulæ; that is, to terms of nature dead, and when so much that is unbalanced and confused is being published on this theme, and broadcast over the air.

In these lectures, the author deals first with what he calls "nature lifeless": namely, with the Newtonian concept of physical nature, and traces therefrom the modern developments of physics. He says "the topic of every science now is an abstraction from the full concrete happenings of nature. In the study of inanimate nature, our attention is directed to details of pattern, measurement and proportionate magnitude, and the laws of nature are merely all-pervading patterns of behaviour, the shift and discontinuance of which are beyond our ken. Nature discloses to our scrutiny merely activities and process." "What do these mean?" he asks, "What is being affected? It cannot be that these activities are merely the formulæ of the multiplication table—merely a bloodless dance of categories. Nature is full-blooded. Real facts are happening."

To this difficulty his answer is that "nature considered in abstraction from life is an activity in which nothing is effected. There is merely a formula for succession, but the lack of an understandable causation to give a reason for that formula for that succession. There is the routine described in physical and chemical formulæ and in the process of nature there is nothing else." All of which illustrates, he says, that a dead nature can give no reasons.

"The sharp division between nature and life, deriving from Descartes and from Newtonian physics, has prevented science from seeing that nature needs the fusion of physical nature with life and has tainted all subsequent philosophy. Life brings into nature individual enjoyment, aim and creativity. Without these there is nothing but mere rules of succession with no demonstrated necessity for the succession."

From life, Whitehead proceeds to the consideration of mind and refers to the purpose of which we are all aware as directive of our actions. "Apart from such direction no doctrine could in any sense be acted upon, and notions mentally entertained would have no affect upon bodily actions."

"In our fundamental observation a sharp division between mentality

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and nature has no ground. The human individual is one fact and not two. We find ourselves living within nature, and must conceive mental operations as among the factors that make up the constitution of nature. There are no idle wheels in nature, and we must accept that every new factor that emerges in it makes a difference."

Life must be distinguished from mentality, which is but a variable ingredient in it. Mentality involves conceptual experience: that is, the entertainment of possibilities for ideal realization in abstraction from physical realization. The most obvious example of conceptual experience is the entertainment of alternatives, and Whitehead enlarges this theme in a striking passage. "In this entertainment mentality reaches its highest development and becomes the entertainment of the ideal, and shows itself in various species, such as the sense of morality, the mystic sense of religion, the sense of that delicate adjustment which is beauty, the sense of necessity for mutual connexions which is understanding, and the sense of discrimination of each factor. The expression of these various feelings produces the history of mankind as distinct from the narrative of animal behaviours. History is the record of the expressions of feelings peculiar to humanity."

It is not possible now to give an adequate impression of the penetration and wisdom of these lectures.

Whitehead seems to me pre-eminently the biologists' philosopher, perhaps the only one who, finding himself intellectually obliged to accept the concept of mind, does not treat it in a vacuum, as an abstraction so separated from its relevance to the totality of human experience that it destroys its own basis of survival.

Amongst modern scientific thinkers of the first magnitude he impresses me as a rather lonely figure, whole-heartedly and candidly prepared to follow truth wherever it may lead him. For him, philosophy remains the vigilant critic of the abstractions of the special sciences.

Now no one would pretend that we have in this philosophy the clear or final solution of the body-mind problem, but at least it offers us a courageous and inspiring approach to this; one that may lead us back to classic sources.

With this long, but, I trust, not too obscure introduction, we come to consider the body of electro-physiological information and hypothesis, largely associated with the new term, Cybernetics, and finding its so various expressions in such writings as those of Wiener, Pitts and McCulloch, in Professor J. Z. Young's Reith Lectures and in Ashby's recent book, "Design for a Brain."

Perhaps the shortest possible statement of the relevant conclusion drawn from all this work and hypothesis is that "nerve nets can know

universals," and in thus knowing them may be assumed to have taken over the business of what Aristotle and Aquinas knew as the active intellect.

"Nerve Nets May Know Universals"

To say that nerve nets may know universals and to draw thence the inference as to mind that I have briefly stated, is perhaps to use a new terminology rather than to provide a fresh idea, but the importance of the present statement is that it is now accompanied by a claim to provide the reasoned grounds in support of what was previously simply a speculation.

It becomes essential, therefore, that we should realize how far-reaching are the conclusions that are being drawn from the evidence.

There are numerous readily available expositions of these, and I choose one, typical in its assurance, recently published in this country in a volume of essays entitled "Perspectives in Neuropsychiatry." In this, we read that the description by Pitts and McCulloch of neuronal nets by which nervous systems know universals is—and here I quote—"of revolutionary significance for natural science, moral as well as natural philosophy, and for one's theory of the normative factor in law, politics, religion and the social sciences . . ." It continues, "The basic premise of philosophical idealists and realists and of scientific naturalists and mechanists to the effect that natural and biological systems can have neither knowledge of universals nor normatively defined and behaviour-controlling purposes must be rejected . . . A teleological system can be, and in human nervous systems it is a mechanical system in which the behaviour of the system is controlled by a negative feedback over the goal."

It is not necessary that I should remind this audience, than whom none knows it better, that when dealing with the records of experimental work upon the cerebral hemispheres, the reader must always carefully study whether the inferences offered as to function flow from the facts recorded, or are logical or compelling inferences. The follower of Jackson knows too well how often in this difficult field the inferences have proved not to be just or adequate generalizations from the facts of observation.

This perplexing problem meets us here in an unusually difficult form, for the theorists have crossed the frontiers of physics and physiology, and have taken their operative term from a profoundly different discipline, namely metaphysics. The term "universal" has a long and striking history in the grammar of metaphysics, and the concept it symbolizes has been a battleground for philosophers and philosophasters of different schools over the centuries.

Now the introduction into a special science of terminology from another discipline is always a source of danger and possible confusion,

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and one can almost feel sorry for those light-hearted biophysicists and physiologists who have adopted this philosophical term. Did they really know what they were about? Did they study the pedigree and history of this term? In short, do they know what it means?

I am forced to the conclusion that a fatal weakness in the claim that nerve nets know universals lies in the failure of those who make it to understand the nature of universals.

Let me be clear. It is not in its possible applications to the understanding of the dynamic processes in nerve networks that I criticize Cybernetics, but in its value or relevance to the problem of mind. We need not doubt that the analogical thinking displayed in the expositions of Cybernetics, and in the comparison of the brain to a computor, has its value as a stimulus to physiologists.

Of course, the trend of thought revealed in Cybernetics is not wholly new, and it is certainly widely spread. In what is known as the Hixon Symposium (1951) on "The cerebral mechanisms in behaviour," there is a paper by Professor Lashley wherein he makes this confession of faith: and I emphasize the word "faith" since few scientists have the insight or the courage to use it in speaking of their scientific hypotheses. This is what he says: "Our common meeting ground is the faith to which we all subscribe, I believe, that the phenomena of behaviour and mind are ultimately describable in the concepts of the mathematical and physical sciences."

With all respect to this so distinguished figure amongst the scientists in our field, it still seems to me that our deepest intuitions tell us that these concepts are peculiarly unfitted to embrace the concept of mind. I cannot make this particular act of faith about them, nor do I see the grounds on which I should be invited to do so.

It may well be for those who feel as I do upon this matter, that our scepticism in this regard is born of what has been called "the unwritten philosophy" that each one of us possesses, but whether this be so or not, we are fortified by the knowledge that most mathematicians and physicists do not hold such ambitious ideas as to the potentialities of their sciences, and are far more modest about their capacity to generalize the cosmos or the microcosmos, Man.

In truth it is largely the amateur mathematicians in the field of biology who, misled by the fact that biological events can often illustrate mathematical formulæ, erroneously conclude that these formulæ have an explanatory value.

Underlying this illusion is the arbitrary doctrine, derived from Galileo and Descartes, that all the special sciences are ultimately reducible to physics, and that all statements that cannot be expressed in mathematical

symbols are nonsense. Yet, it has been pointed out that if a unified science is ever formulated, we cannot now foresee in what grammar it will have to be couched, and in any case this hope is no more than a hope and not a matter for pronouncements.

Yet in our situation it requires some strength of mind not to be intimidated by the current of authoritative opinion now setting in favour of a physical and statistical account of mind, and we may easily take the evidence too seriously and allow the frailty of the logic to escape our notice.

Indeed, for the physician whose days are spent amidst the dramas of human lives, there is an unacceptable naivety in the mechanist view of mind, something affronting to his common sense and experience that makes him feel more sympathy with such a rhetoric as Hamlet's:

> "What a piece of work is a man! How noble in reason! How infinite in faculty! In form, in moving, how express and admirable! In action how like an angel! In apprehension how like a god! The beauty of the world! The paragon of animals!"

Yet if that simple country yokel, William Shakespeare, had enjoyed the advantages of living in modern Chicago instead of in Stratford-on-Avon in the backward Elizabethan age, and had learned there that all he was ranting about was a simple matter of some feedback mechanisms in the cerebral cortex, how much less emotively he might have written, and what a deal of dreadfully unscientific poetry we might have been spared.

The electronic age has yet to produce its poets, and I suspect that I shall never feel the urge to read their works. Their sonnets will doubtless be couched in mathematical symbols, and if any of them essays another play of King Henry the Fourth, all he will be able to tell us about Falstaff is that he was πr^2, presumably with a plus and a minus sign in front of it to lend statistical precision to the definition of nonentity.

In short, we may not refrain from closely examining the claim that nerve nets can know universals, for hitherto the Universal has been regarded as the primary, the elementary activity of the immaterial intellect.

Universals

None but the professed philosopher could hope to deal adequately with the problem of the Universal, or to expound the widely differing views that have been held as to its nature and varieties and its place in epistemology.

Therefore, since I am not a philosopher addressing philosophers, I shall confine myself to such elementary considerations as are within my scope and are essential to the development of my theme.

For some mediæval philosophers, the Universal was no more than a name, a mere *flatus vocis*, referring to nothing in nature or in ideas, whilst for others it is no less than that first essay in abstraction from sense data and images that marks the intervention of mind, of a noncorporeal analytic element in man which is yet an integral part of his nature. This view indeed represents the main current of European philosophical thought from the earliest to our own times, though there have been notable deviations from it.

Expressed in its simplest form, the Universal is *one thing common to many;* the actual recognition of the one thing common to many is the universal idea. In this context the "one thing" denotes a nature or essence of some sort that is actually shared in by many. It is not the collection of the many into one: it is the distribution of the one into many. These natures common to many things are known as universals.

The concept of the one common to many is known more precisely as the Metaphysical Universal, and a further degree of abstraction brings us to the recognition of the predicability of the one common to many.

The Metaphysical Universal may be used apart from predication, simply as expressing a common nature individuated in many things, and to these it may have relations of three orders. It may be a sign or symbol, such as a general term. It may be a causal universal: that is, a cause common to many things, or it may simply express the nature common to many things.

In so far as this nature can be predicated of many things, it is known as the Logical Universal.

Now the metaphysical and the logical universals have this in common that they exist in the mind, but in all other respects they are different. The metaphysical universal, as we have seen, signifies nature or being as it is abstracted from singular things, without taking into account its relations to these things.

On the other hand, in the logical universal it is this very relationship of the universal to its inferiors, the individuals, which is its formal constituent. Therefore to know universals is to know two things: It is (1) to know the nature, essence or being of things, that is, to know that which is the essence of a thing without which it would not be what it is, and (2) to be able to recognize and predicate common qualities of singular things.

Hitherto, it has been generally held that it is the intellect which makes the Universal, which abstracts from sense data and from the images provided by the senses the qualities which are common to them, predicable of them and essential to their being.

With this elementary account of the Universal, we may proceed to

ask which of these knowledges it is that the activity of neuronal circuits is supposed to provide.

It is, perhaps, not surprising that in the relevant literature we find no answer to this question, nor, indeed, any sign of awareness that it exists and demands an answer.

We find the term used indifferently in both senses, and also used of things that are in no sense universals. Thus, in the volume of essays already cited, "Perspectives in Neuropsychiatry," we find the Cybernetic thesis stated as follows: "A self-re-exciting loop of neurones, sharing neurones with other loops in which reverberation can be set up by the entry of afferent impulses from different sense receptors, gives and preserves the association between different particular events and allows the recognition of a universal to be sparked by the receipt of a particular. Thus, the sight of a cat, whatever its colour or size, the written or spoken word for it in any of the languages known to us, the sound of its voice in the night, the feel of its fur in the dark, and, alas! its smell, will inform us of the same universal."

Here, surely, is great confusion. All the enumerated data of sight, sound, touch and smell, inform us of an individual, a particular cat—it seems, a smelly cat, and no question of a universal arises from this neuronal activity. Further, to hear or see the verbal symbol "cat" is a different experience altogether, possible only to man, for whom it may or may not lead on to the concept of the universal.

The mental recognition of a universal is the recognition of a reality which is not individual, though it is "one," nor identified with an individual, even though it does not exist apart from individuals and is not a mere collection of individuals.

However complex the activities of neuronal circuits, their stimuli are and remain individual and even material. No amount of "sparking" in the circuits can produce a concept of something which of its nature transcends the individual.

But it is not alone in this connexion that we find misunderstanding of the Universal in our literature, for in another essay in the same volume the general question of recognition of universals by man and animals is taken up by another of the symposiasts.

Thus, we read: "The dog is employing a universal when he reacts to a cat," and again, following upon a citation from Kant, the essay continues, "Kant is here describing the process of abstraction by which the general concept of a triangle is derived from various instances. This process is not peculiar to man, for a rat can be trained to recognize triangularity."

Further we read "We may suppose that between a rat recognizing

triangularity, a dog employing a universal in its behaviour to a cat, and man entertaining the idea of a dog, there is a transition from the less conscious to the more conscious."

Surely, here the natures of percept and concept, of singular and universal are confused.

I concede that a dog recognizes a cat, but I deny that in so doing it employs a universal. I concede that a rat may react to a triangle, but I deny that it recognizes triangularity.

I deny also that the difference between a dog and a rat doing these things and a man entertaining the idea of a dog involves no more than a transition from the less to the more conscious. To entertain the idea of a dog is essentially a conceptual activity, and there is no transition from percept to concept, for of its nature the percept is a singular and cannot become a universal.

The situation is still further confused when the writer adds that "it seems likely that the rat responds to triangularity unconsciously and without the intervention of conceptual thought."

Surely, to maintain that the rat can entertain the metaphysical universal without conceptual activity does not make sense.

In fact, even the simple statement that the rat recognizes triangles is correct only with limitations, for example, it has been found that if the triangle is tilted on its side, or when a black triangle on a white ground is changed to a white triangle on a black ground, all discrimination is lost.

The statement that the rat recognizes triangularity is to be found not infrequently in the literaure, and how much more than ascertained fact it contains is clearly shown in Vernon's recently published work, "A further study of visual perception." Both factually and logically, then, the statement cannot be accepted.

Where, then, does this point of view, with its implied anthropomorphism and its misunderstanding of the nature of universals, lead us if we follow it to a logical conclusion?

We should have to suppose that the earwig in our garden employs the universal, "dahlia," and the greenfly the universal, "rose." In effect, the term ceases to have a meaning.

It is upon this misunderstanding, then, that there rests the hypothesis that neuronal circuits, or animals, know universals.

Yet we may dismiss the hypothesis on other grounds than those of terminological inexactitude and the ensuing confusion of thought. We may ask whether biological studies confirm the claim that animals know universals, or that man, who does so, knows them solely in virtue of the activities of his neuronal circuits.

In general, biologists do not find that animals know universals. Whitehead reminds us that animals enjoy structure but only man understands it.

There are no grounds for believing that animals react in virtue of any abstract consideration of the problems facing them. They show determinate ways of acting, as for example, in courting, mating and nesting and so on. In any true sense of the term they show no originality.

Until we know far more of the physiology of visual patterning than we do, it is premature and unscientific to invoke conceptual activity, or a knowledge of universals as factors in such visual discrimination as animals display.

Vernon's and Lashley's (1938, 1952) critiques on this subject do not point in this direction.

Yet whatever conclusion we reach about this, it might still be argued that since man does know universals he does so by the activity of his neuronal circuits alone.

I believe that there is a short and conclusive objection to this view. The constitution of the nervous system in man, its essential make-up, is not qualitatively different from that of the rat. There are no grounds for thinking that neuronal circuits in the human brain engage in dynamic processes qualitatively higher or different from those in the rat brain. Yet how profoundly different are man's conceptual powers from anything we can glimpse in animals.

Whoever ponders this problem must find himself recurring to another of Whitehead's lucid statements, thus: "When we come to mankind, nature seems to have burst through another of its boundaries. . . . The conceptual entertainment of unrealized possibility becomes a major factor in human mentality. The life of a human being receives its worth, its importance, from the way in which unrealized ideals shape its purposes and tinge its actions."

The most that can be claimed for neuronal circuits is that they integrate the ceaseless flow of afferent impulses from the different receptive fields. They are the refining machinery of sense data, and, as Head proposed, provide a new construction which is presented to consciousness, but they do not and cannot provide conceptual knowledge as such, nor include any appreciation of the universal as such.

Here no nerve networks, however, complex can serve, for we pass out of the material world in which alone they can function and find ourselves in an immaterial world of ideas. The bridge between the two necessarily implies the existence of non-material faculties capable of effecting the transformation.

Thus is it that from sheer psychological and philosophical necessity, traditional common-sense philosophy from the earliest Greeks to Aquinas

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accepted the existence in man of an essential immaterial element, capable of such transformation and setting him above the merely animal. This element they called psyche, entelechy, anima or soul.

It has also to be recognized that for the soul's functioning as an essential element in the hylomorphic human person, it needs sense data, of which the brain is the collecting, integrating and distributing mechanism. Yet it would be quite childish to identify the instrument with its user, even though the user be dependent upon the instrument for operating.

The Mind and the Computing Machine

Time does not allow a discussion of the many cogent criticisms that have been made of the analogy offered between computing machines and the brain.

It is always easy to make analogies and logical statements from them, but quite another thing to correlate these with the dynamic processes in living nervous systems.

It has been pointed out that while these machines may represent our logical and mathematical concepts symbolically and facilitate their handling, it is nonsense to speak of their thinking since they require a human intelligence to read off their collocation of symbols.

The suggestion that the mind or brain is a computing device which models by its symbols the external world, seems to be an attempt to describe the mind in terms of a very special and limited type of its own symbolism, that of logic and mathematics. The greater is subsumed in terms of the less, and the manipulations of strings of symbols according to the rules of a specific calculus is now being taken to be identical with thought itself (Mays, 1951).

How remote from experience and common sense these abstractions may be we see in the monograph, "Design for a Brain" where the author makes the two following defining statements: (1) No teleological explanations for behaviour will be used. It will be assumed that a machine or an animal behaved in a certain way at a certain moment because its chemical or physical nature at that moment allowed it no other action. (2) The biologist must view the brain, not as being the seat of "mind," or as something that "thinks," but, like every other organ in the body, as a specialized means to survival.

Yet surely the first definition nonsuits the author from invoking the teleological concept of the brain as "a means to survival."

The term "survival" implies life, but life has no place in the author's basic concept, and he is simply making a misleading use of symbols when he employs the term.

Surely, it is not by semantic exercises of this order, backed up by no matter what heavy mathematical batteries, that any realist or valid concept of mind can be reached. In words I have already quoted, these abstractions are so remote from the totality of experience that they destroy their own basis of survival.

The Concept of the Soul

If, then, as I believe, we cannot invoke nerve nets as able to know universals, we must either abandon the quest for an account of mind that shall explain its place in man's nature, or look elsewhere for it than in the concepts of physiology, physics or mathematics. We must abandon the assumption that the human person is nothing more than a focus for the hurrying to and fro of molecules, or his mind no more than a bloodless dance of action potentials.

Do we, then, after all this, find ourselves back with Jackson, Sherrington and those other cautious scientists who confess that they have no answer to our problem? In a limited sense we are back with them, but we are not compelled to halt with them.

We have seen the scientist making his act of faith that ultimately the problem of mind will find its solution in the concepts of physics and mathematics. Each of us has the right to make his own act of faith, and mine is this, that these concepts are of their very nature incapable of subsuming the activities of the human mind: to think that they can by addition become so is an illusion: and, finally, that we shall have to accept the ancient concept of the soul again: as an immaterial, non-corporeal part of the human person, and yet an integral part of his nature, not just some concomitant aspect of man, but something without which he is not a human person.

If, then, I subscribe to the belief that man has a soul not to be interpreted in terms of nerve nets, and to the belief that there are values in his life, religious, ethical and æsthetic—not to be comprehended in terms of action potentials—it is not that I lag behind my electronically minded brethren in neurology and am sunk in a mire of mediæval superstition, or obsessed by a crude animism that sees gods riding in the storms and demons in the droughts, it is rather that I prefer to remain in the strong and ancient current of European philosophical thought, and that I am not ready to confine the Universe in the procrustean bed of those proximate causes which seem to many scientists all there are to be sought.

After all, the mechanist concept of mind—or rather of a mind substitute—does no more than provide an analogy for certain particular effects, though it is now offered to us as a complete account of the human mind.

This is the voice of the Peter Pan school of science, the exponents of which do not grow up, but are now always popping up before the footlights, beseeching us to believe in their electronic fairies, lest their naïve hypotheses die untimely.

How this immature outlook obtrudes itself into the literature of our subject may be seen on the jacket of a recently published monograph on the cerebral cortex of man, where the reader meets the following proposition, quoted from a back number of the "Scientific American": "If the proper study of mankind is man, surely the supreme biological interest of man is his brain, particularly the grey cortex of two billion cells without the orchestration of which there can be no thought, no sweet sonnets of Shakespeare, no joy and no sorrow."

What a typical materialist's half-truth! What a pregnant silence about the other half, for, from the dumbest blond to the wisest sage, each one of us has a quota of two billion grey cells, yet the human race has produced but one Shakespeare.

It is not my role, nor is this the time, to seek to expound the place of the immaterial element in man: the soul, as this has come down to us throughout the centuries from Aristotle and Aquinas: a concept that does not involve a crude dualism, but a true holism. All I wish to say is that I do not see how we can form a concept of the human person, as one unique fact, on any other ground. I am, in reason, as entitled to believe this as to entertain the groundless hope that natural science will at some indeterminate time and in some wholly unforeseeable fashion, provide the answer for us.

Science will have to re-establish its necessary relation with metaphysics before this can happen, and should that come about, the natural scientist will realize that *by itself* his discipline does not and cannot contain the answer to the riddle.

Conclusions

There is a sense in which the present is an age of which a characteristic is its failure to understand the status of its own abstractions, and this, perhaps, is the inevitable fruit of the divorce of natural science from metaphysics, to have achieved which was the empty triumph of the nineteenth century.

Thus, those who are outright opponents of the notion that there must be an immaterial element in the human person have, for the most part, no language in common with those who think otherwise. For the problem involved is essentially metaphysical, and for the materialist metaphysics are sour grapes.

There are others, however, who content themselves with the criticism

that it is a sterile and pessimistic attitude to maintain that physics and mathematics are inadequate to subsume the human mind.

Thus, Brosin, summing up the Hixon Symposium, speaks of the "pessimism" of Sherrington and of Adrian in this regard. Grey Walter (1952) contrasts what he calls "the optimistic, constructive, imaginative tendency" of those who think with him that "it is only a question of careful observation and patience, and of technical refinement, before we can observe as electrical discharges the thoughts of our own brains," with the "negativistic, agnostic or mystical attitude which in the extreme leads to sterility and inaction."

We need not deny our tribute to the choice of commendatory adjectives the writer bestows upon those who feel as he does on this matter, but what are these adjectives doing in a scientific discussion?

In the strict sense, optimism is the ascendancy of good, as pessimism is the ascendancy of evil. It is true that in conversation these terms have been trivialized to mean no more than euphoria and depression, and it is presumably at this banal level that we find them here employed.

Yet in science, hypotheses are neither good nor evil, cheerful nor dismal. They are simply truth or error, or both mingled. It is odd to find those who equate mind with electrical potentials, and who look forward to the day when they may subsume mind in the austere symbolisms of physics and mathematics, now lapsing so inconsistently into these ethical and emotive categories in their discussions.

Finally, to conclude this argument, we may say that if, as many hold to be an inescapable inference from reason and experience, mind cannot of its nature be describable in the terms of physics and mathematics, how does it come to be sterile to say so?

Such an attitude is realist and offers no obstacle to the rigorous investigation and rational interpretation in their own grammar of physiological phenomena.

After all this, I cannot but be aware that my views must fall upon some hostile ears, and that many will be unwilling to follow me beyond the predetermined limits of their intellectual journey.

Perhaps the barrier that stands between me and the scientific materialist is his conviction, deep though not grounded upon reason or experience, that natural science is the destined heir to the ultimate interpretation of all things in Heaven and Earth, and for him of necessity, therefore, the music of the spheres has to be canned music. An unpleasing thought that brings me in conclusion to that most lovely passage in "The Merchant of Venice" where in the final scene Lorenzo and his Jessica sit on a grassy bank in the moonlight.

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Says Lorenzo:

> "Sit, Jessica; look how the floor of heaven
> Is thick inlaid with patines of bright gold:
> There's not the smallest orb that thou beholdest
> But in his motion like an angel sings;
> Still quiring to the young-eyed cherubins;
> Such harmony is in immortal souls;
> But, whilst this muddy vesture of decay
> Doth grossly close it in, we cannot hear it . . ."

For me, the chill physico-mathematical concept of the human mind is a muddy vesture of decay in which I am not willing to be enfolded. It is unworthy of the dignity of Man.

And if any say that this is not a scientific attitude I am unmoved by the irrelevance, for, outside its proper field of discourse, the word "science" does not intimidate me.

Man was not made for science, but science by man, who remains more and greater than his creations.

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TACTILE THOUGHT, WITH SPECIAL REFERENCE TO THE BLIND[1]

BY

MACDONALD CRITCHLEY

Although the hand is man's most efficient palpatory tool, it is actually not the most sensitive region to tactile stimulation. In many respects, the lips and the tip of the tongue are more sensifacient, and even the power of tactile discrimination is more delicate there than over the pads of the fingers, a fact utilized by blind persons in threading a needle, or in studying the intimate structure of flowers and plants. None the less, the fingers and hand, and not the buccal mucous membrane, represent the conventional palpatory organ of man. Even the skin of the cheeks and brow may have a lower threshold for tactile and thermal stimuli than the hand. Perhaps this helps explain Bender's phenomenon of rostral dominance, whereby of two touches simultaneously applied to face and elsewhere, the one over the face is usually the only one observed. But however sensitive the skin of the face, it is not ordinarily used as a means for identifying tactile contacts. Indeed, only with the so-called facial vision of the blind (sixth sense, *Fernsinn*, or sense of obstacles) does trigeminal sensitivity come to the fore (and, even then, it is probably subordinate to acoustic impressions).

One must distinguish between liminal intensity, discriminative sensitivity, and the power of identification of tactile sense data, especially those of an idio-significant or symbolic character. This is well shown in the blind. There is little or no evidence that individuals born without sight, or those who have lost their vision at some later age, are more "sensitive" to tactual stimuli than the sighted. Even the compass-test ordinarily reveals no differences in the liminal distance between blinded and sighted individuals. And yet, the blind person may be able to run his fingers rapidly over an array of embossed points, identify them as verbal symbols and interpret them. A sighted person who touches a page of braille print feels just as many points as a blind person. But while to the one it is utter confusion, to the other it is an orderly arrangement of punctographic

[1] From the National Hospital, Queen Square, London, W.C.1, being the Presidential Address delivered before the Section of Neurology, Royal Society of Medicine, October 2, 1952.

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semantic units. With tests for stereognosis, the problem is more complicated. Personally, I have never met a blind person whose power of identifying objects by touch was better than, or even quite as good as, a normal subject. And yet, of course, a blind person lives much more in a world of touch than does a sighted individual. There is evidence, however, that a few exceptional blind subjects possess a heightened, and almost uncanny, power of stereognosis.

Diderot told of a blind man who could identify antique coins and medallions, and distinguish the genuine from the fakes. Helen Keller—deaf, dumb and blind—studied with great interest not only statuary, but the bas-reliefs on Greek vases.

To an intelligent blind man even a simple static contact with an object may arouse a wealth of apperceptive detail. The blind Professor Villey said that, by placing a finger on the corner of a table, he could at once conjure up an image of the whole room with its furnishings. This is an extreme instance of the unconscious formulation of sensory impressions by way of the stimulus of a single "critical detail." It does not surprise us, therefore, to learn that the autopsy on Laura Bridgman (who was a deaf-mute as well as blind) showed a conspicuous over-development of the parietal lobes, as compared with other regions of the brain.

The problem goes even deeper. Just as the sighted person senses with the pulp of his forefinger only a meaningless jumble of dots—and his tactile discrimination is by no means inferior to that of the blind subject—so also, the blind person who passes one of his *non-reading* fingers over the page of braille cannot interpret the embossed signs that he feels. In other words, braille reading is a learned function of only one limited part—usually the index finger of one hand or the other; less often, of both hands. The blind student who by touch can interpret braille symbols at the rate of say, 60 words a minute, performs poorly, if at all, when he uses his thumb, or the 2nd, 3rd or 4th finger. And yet the threshold for tactile discrimination is not very different over the pulps or "tactile rosettes" of all the fingers, whether one is speaking in terms of two points simultaneously applied, or of more than two points. Clearly then, some cerebral process is at work which transcends mere tactile discrimination, as subserved by the parietal cortex.

A number of observations upon what might be termed the neurological aspects of braille reading may therefore be cited:

(1) It must be emphasized that the empirical invention of braille typology stands very near the limit of normal tactile discriminative powers. Each symbol, and there are sixty-three of them, is made up of one or more bosses within a "cell" or cluster of six possible places. Only a few signs comprise one point: many are made up of 2, or 3, and some of 4

or 5 dots. Now 6 points happens to be the normal limit of the power of discriminating separate contacts at a single, synthetic, immobile contact. This takes place by a process of immediate subitizing of separate stimuli. Of course, if the exploring finger moves, synthetic touch becomes an analytic touch, and stimuli beyond the figure of 6 can slowly be appreciated. Louis Braille's empirical invention still further keeps within physiological capacities in that his embossed dots are set at a distance of either 2·5 mm. or 3·0 mm. apart: we remind ourselves that the minimum distance which constitutes the usual threshold of tactile discrimination over the pulp of the fingertips is about 2·0 mm. Each symbol, therefore, stands always just within the bounds of human achievement; but when one recalls that, in reading a page of braille, the blind person is sensing and interpreting about 2,000 to 2,500 embossed points a minute, the degree of accomplishment can be appreciated.

To illustrate the delicacy of the discriminatory powers called upon in braille reading, one may take the symbols standing for the consonents *RS* which are: ⠗⠎ To the beginner who places his finger-tips upon this complex, the three vertical dots tend to merge into a sort of irregular linear impression, while the point farthest over to the right, and the one most over to the left, are felt as distinct and separate elements. The tactile impression is rather vague, the intermediate elements being blurred; and the first symbol "R" tends to be confused with the succeeding symbol "S." If the palpating finger is not held accurately in line with the long axis of the punctographic cell, the difficulties increase. As soon as the finger-tip is moved, however, and the beginner makes his exploratory touches across, up and down, and around the cell or adjacent cells, then simultaneous touch becomes successive touch, and the morphological arrangement of the dots becomes clearer. So eventually their symbolic identity is realized.

(2) The practised braillist is able to read with his master finger, rapidly and accurately, up to maybe 100 words a minute. He can still do so, even if a cloth is interposed between his finger and the page: or, indeed, even if he wears gloves and then reads through an intervening piece of material. In many blind persons, the master finger is exclusively one-sided, though well-taught braillists should be able to read with either index finger. Even so, there is always a manual preference, the hand of choice reading faster than the other. In nearly three-quarters of bi-manual braille readers, the left hand is the one preferred. Ordinarily, the left forefinger hurries ahead and reads half of one line, which is then completed by the right finger, the left finger having already dropped down to the start of the next line of print. In other braille readers, one forefinger, say the left, marks the beginning of each line, leaving the other

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forefinger to act as interpreter. Yet another technique is for the right forefinger to sweep briskly across the page, interpreting the easy symbols, leaving the left forefinger to follow and to help identify unusual collections of symbols, by means of swift small-range searching movements. In this case, the one finger is devoted to the "service of recognition," and the other to the "service of control."

The blind person who relies upon one hand exclusively for braille reading may explain his difficulty when the other hand is tried, by saying that "all the characters seem to be reversed." And yet this same individual can probably identify a line of braille characters by moving his master finger in the opposite direction, that is from right to left. This act will be performed easily, although each symbol in turn must have appeared reversed to the horizontally moving finger.

The speed of braille reading is ordinarily increased by dint of skipping details and employing guesswork, based either on the initial letter, or on the length of the word, or on the context. A symbol-for-symbol interpretation is dispensed with, without detriment to the sense of the subject-matter. This process differs but little from the sighted person's ability to hoist in the meaning of a sentence as a whole without reading each individual letter or word.

(3) As the blind reader passes the finger-tips of his two hands over the page of braille type, it may often happen that actually the tips of several fingers simultaneously touch the punctographic symbols, but of these many finger-tips, only one is "attending to" the nature and meaning of the symbols. The sense data from the other fingers are neglected, or disregarded: some might say "repressed" or "extinguished." Other braille readers adopt a different technique and keep some or all of the non-reading finger-tips off the page. Possibly no two braille readers adopt exactly the same style. However, with most blind readers, there are more cutaneous areas simultaneously stimulated than are essential for reading purposes. We can detect here two of the fundamentals of sensory patterning as described by Lashley, namely: (1) a selective emphasis of parts of a total mass of excitations into coherent and dominant patterns; and (2) selective pruning, that is, anticipatory sensitization of a receptive mechanism to specific patterns.

(4) Although it has been said that the pulp of one or more fingers "learns" to read the meaning of braille symbols, the "learning" process, of course, does not reside in the finger-tips, but in the cortex. Or, in any event, it is transcortical. The physiological mechanism behind an acquired sensorimotor co-ordination of this sort is still debatable. Some would imagine a firm concatenation of cortico-cortical neuronic linkages, a closed

system of excitation, representing a sort of trail blazed by long practice. Others would think in terms of electrical fields set up by patterns of neural activity. Whether there occurs an actual morphological adaptation, such as an enlargement of certain groups of cells or of their processes, is uncertain and, I submit, improbable. Any hypothesis of engrams, schemata, traces or models necessitates an anatomical determination, in that cortical neurones activated by stimuli to the forefinger must form the basis of any mnemonic trace, or prepared pathway, or while the remainder of the cells are not concerned. This may be so; but nevertheless, it must be realized that, after a relatively short further period of learning, other sets of cortical neurones can be sensitized so as to form comparable traces. In this way, the braillist who ordinarily reads with the pulp of one index finger may readily pick up the trick of learning to read braille with another finger: or with the thumb; or with his toes; or even with the tip of his nose, or his tongue.

This observation exemplifies two other fundamentals of patterning which Lashley has described, viz.: (1) that of stimulus equivalence; whereby the effectiveness of a pattern within any receptor system for behaviour is determined by their proportions of some other generalized character, and not by the specific receptor or cortical cells excited; and (2) that temporal sequences and spatial patterns are interchangeable.

Transmissibility (or transformation) of the learned tactile effect is analogous to the ordinary experience in the visual sphere, whereby a common object—e.g. a dinner-plate—can be optically identified as such, even though it be rotated upon its axis, or tilted so as no longer to present itself as a circular object. The visual Gestalt is none the less accepted unhesitatingly, by dint of a process of generalization, or abstraction. It is now a commonplace that even a rat can be taught to recognize the symbol of triangularity and to select a three sided figure (whatever its relational properties, that is however orientated, and whatever its dimensions). Lashley's recent work shows that highly complicated powers of accurate discrimination of visual patterns can be attained by a rat.

Similar phenomena occur in the domain of ordinary stereognosis. At one end of the scale is the case of the adult who has grown up with an infantile hemiplegia. No sensory defect occurs except for the so-called "virgin hand," or astereognosis from inexperience. At the other extreme is the normal stereognosic ability which is essentially a manual aptitude. But in certain conditions, this perceptual achievement can be acquired in other segments of the body. The sole of the foot, or the integument of the trunk—areas which ordinarily are not used as organs of sensory identification—can be trained to do so. Practice can bring about a remarkable degree of manipulative skill, coupled with stereognosic ability. When

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congenital dysplasia, or injury or disease at a very early age, deprives the subject of the use of the hands or upper limbs, the stumps, or perhaps the lower extremities, can acquire astonishing dexterity. This was well shown in a case of mine with acro-cephalo-syndactyly (Apert's syndrome) where a most delicate degree of tactile discrimination was possible over the quite rudimentary stumps which constituted the upper limbs.

(5) Through practice, a skilled braillist ceases to pay attention to the constituent dots forming a punctographic cell: he identifies each symbol as a whole—a tactile Gestalt. This fact ties up with the question of the comparative legibility of the various braille signs. That some are easier to read than others is not surprising, but the principles determining legibility are still rather obscure. Bürklen has shown that the mere number of constituent dots is not all-important. For example, "A," represented by one "⠁", and "G," represented by four "⠛" are almost equally legible. Characters comprising simple geometrical shapes are more easily identified than those which are complex. Open characters, i.e. with dots far apart, are better read than comparable signs with their dots close together. Thus, ⠥ ("U") is the sixth most legible sign, while ⠓ ("H") is sixteenth. This observation is understandable if regarded as relative tasks in tactile discrimination. And yet, on the other hand ⠃ ("B") is eleventh in order of legibility, while ⠅ ("K") is twenty-sixth, and ⠊ ("I") is fourteenth, while ⠡ ("AU") is thirty-third. Obviously, some other factors are concerned in the question of legibility which are still obscure.

(6) Sensory perception is largely an appreciation of a change of state. Hence, a moving stimulus is more readily appreciated than one which is stationary; and a stimulus which fluctuates in intensity is felt more keenly than one of uniform magnitude. The effect of a moving stimulus can be achieved by passing the palpatory organ over an immobile object. Movements of touch not only produce a wider receptive target, but also a lowered threshold. These movements may be quite small in range and outside consciousness, but for all that they are powerful adjuvants to the exploratory act. Vibrations, or touch-twitchings as they are more often called (*Tastzuckungen*), are of importance in the tactile world both of the blind and of the agnosic (as in the case described by Goldstein and Gelb). Blind people are perhaps more mobile and restless than sighted ones, for they are constantly adding to their knowledge of the environment by building up a storehouse of tactile and proprioceptive images. These movements may be so exaggerated as to constitute curious stereotyped tic-like mannerisms—"blindisms" as they are called. In braille reading, finger movements are extremely important. Although a stationary finger can eventually achieve recognition of an isolated symbol, a horizontal

sweeping movement assists considerably in perception. When a series of embossed symbols are aligned so as to form words and phrases, a sweeping touch is essential for reading. In other words, a learned faculty is actually assisted by a mobile stimulus. The expert performs a horizontal movement which is uniform in direction, in speed and in pressure. When a less skilled braille reader meets an unfamiliar word, his stroking touch is halted for an instant; pressure upon the symbol increases; and the transverse motion of the finger is replaced by vertical, zig-zag or circular movements of search.

With practice, therefore, random finger movements are the first to be eliminated; and after them, the deliberate acts of search, leading to the behavioural parsimony of an unbroken, transverse sweep.

The rôle of movement in the act of recognition by touch alone is sometimes demonstrable in the different modes of behaviour according to levels of intelligence. The blind subject who is also a dullard may appear to utilize his stereognosic abilities well enough. But if he is given very intricate or unfamiliar objects to identify—say a plaque or domino—he will rely more upon synthetic than upon analytic touch. He names the object promptly if at all, by guesswork as it were, and usually his answers fall wide of the precision which might be expected. With a blind subject of high intelligence, the response is different. Still touching or holding an unfamiliar object, he hesitates to name it: he first explores the edges and surfaces rapidly yet methodically, and after a series of stroking and encircling touches, now exerting a gentle pressure, now measuring and weighing, he goes on to describe systematically the physical properties, or what Galen enumerated as "tangible distinctions" (hardness and softness; viscosity; friability; lightness; heaviness; density; rarity; smoothness; roughness; thickness and thinness). Finally, he puts a name to it.

The rôle of mobility in tactual perception is also illustrated in the case of two-dimensional stereognosis. An outline figure (e.g. a pastry-cutter in the shape of a heart, or ace of clubs), when placed in contact with the body-surface, is rarely felt save as an amorphous pressure. Even upon the palm of the hand, two-dimensional stereognosis scarcely ever evokes a sensitive or accurate perception. But if the figure be outlined upon the skin with a blunt point, then the chances of its being recognized are greatly enhanced. Clearly, a pattern of evoked potentials, fired off by a moving stimulus, is more significant than an identical pattern activated by manifold simultaneous stimuli. An even simpler example may be found, in some pathological states, in the phenomenon of tactile inattention, whereby two simultaneous contacts are felt only as one; whereas, if the two stimuli are applied asynchronously, they are felt as

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two, even though the interval between the two applications be quite short (i.e. one-fiftieth of a second).

(7) Braille reading is often said to be very tiring. Prolonged sessions lead to a generalized feeling of fatigue, but, in addition, a reduction has been described as occurring in the tactile sensibility of the finger-tip. As Javal wrote: ". . . when I have read much, the dots feel like wool to the right index finger, but, on the contrary, like points to the left." This is what Diderot foresaw when he located the blind man's soul within the finger-tips (the theatre of thought), saying that, after profound thinking the digits would probably be as exhausted as the brain of a sighted person. The idea of an altered threshold following prolonged peripheral stimulation is an engaging one and probably was at the back of the minds of Stein and Weizsäcker when they introduced their doctrine of *Funktionswandel.* Bürklen found that such dulling of sensitivity was only slight and inconstant. In the case of older readers not in practice, the altered threshold could be shown by a curve with two peaks. With younger subjects in daily practice, no change in sensitivity could be demonstrated, even after six hours' reading. Of course, the results may be quite different in the case of braille learners.

(8) Braille reading and stereognosis, applied to unaccustomed test-objects, bring up the question of manual preference in the act of palpation. Most blind persons, as already said, prefer to use one hand rather than another for braille reading, and this hand has little to do with the question of ordinary cerebral dominance. Similarly, in his efforts to identify a difficult test-object, the normal blindfolded subject may display a manual preference, and he may occasionally be observed to transfer, in his bewilderment, the puzzling object from one hand to another. With larger objects, the blind person (and also the blindfolded normal) will prefer to use both hands simultaneously, thereby gaining far more morphognosic data than with either hand separately or in succession.

Tactile imagery.—The question may now be raised as to whether a form of imagery ever exists which is purely tactile. In sighted persons, such a phenomenon must surely be most rare. Even in the blind, it is probably uncommon; except in the case of the congenitally blind, where touch stimuli and their recall play a much greater rôle. Here, too, auditory and also olfactory impressions loom so prominently in their mentation that it would still not be correct to speak of a pure tactile imagery. Perhaps the nearest approximation is met with only in the case of those born deaf as well as blind.

In this connexion, the word "tactile" needs amplifying, so as to com-

prise proprioceptive as well as exteroceptive sensations. For such a purpose, the term "haptic" rather than "tactile" (or "tactual") is sometimes used.

Proust wrote that the loss of a sense adds as much beauty to the world as its acquisition. There is no time unfortunately to discuss the fascinating question of pure tactile æsthetics, whether in the blind or in specially sensitive sighted persons; whether occurring in health or resulting from cerebral disease; whether applying to surface textures or to solid objects of pleasurable form.

Vision is biologically so important a special sense that even in those who lose their sight at a relatively early age, a visual type of thinking may continue, or at any rate, it may modify the kind of imagery. The blind person retains a visual frame of reference. Thus, a sightless person who has learned geography by studying the embossed maps in the blind school might be thought likely to develop a mental picture of a country, or a range of mountains, in the form of a tactile impression. A blind pianist might be expected to recall a difficult musical phrase not only by ear but also by way of a tactile image of the braille characters. Even a text in literature might be imagined to call up a faint image of the punctiform symbols. These are what might be expected, but it is doubtful whether this actually is the case. Most blind persons probably construct an "image of a visual image", even of faces, persons and scenes they have never had the opportunity of appreciating visually. To one who is blind, a particular person may be represented imaginally not only as a "voice", clothed in the bodily contours of which they may or may not have had tactual experience, but as a visual convention . . . a faint symbol which may bear but few resemblances to the original. This "optification" of tactile data is regarded by Révész as a process of transposition of haptic into visual impressions. It may appear in passive or active form. To some extent, it may prove, if too vivid or too obtrusive, somewhat of a handicap to the recently blinded person who is trying to learn braille. Visualization is often quite vivid even though the patient may have been blinded early in life and thus have had a relatively short background of visual sensa. Furthermore, visual experiences are not constantly being renewed, and yet these remote sensory experiences linger and continue to influence powerfully the nature of the imagery.

This explains why blind persons commonly speak of "seeing" a page of braille, or a person, or place, when they really mean "touching," "experiencing" or "feeling." The blind-deaf are probably less well endowed with this pseudo-visual form of imagery. And yet, Helen Keller's writings contain a profusion of terms which must surely have been beyond her experience. Her abundant references to colour, luminosity, tone and so on should probably be looked upon as "verbalism"—that is,

an affectation, an over-compensatory use of visual metaphor in her prose. Homer's frequent use of the expression "wine-dark sea," and "black pains," may be another instance of verbalism, or, on the other hand, it may be taken as evidence that he was not a victim of congenital blindness.

Verbalism is not a universal rule, however. The work of W. H. Coates, the blind poet, shows that forceful and vivid ideas may be couched in a purely tactual terminology. He even re-wrote a sonnet of Shelley's, replacing every visual metaphor by recourse to nothing but the language of tactile thought.

This process of "optification" brings up for discussion many interesting ideas, including the synæsthetic imagery of the blind; their elaborate number-forms and photisms; their complicated visuo-tactile dreams; and the phenomenon of the "inner eye" of those who have lost their sight late in life (the Erlebniswandel of Jacob). We are reminded of Werner's suggestion of a fundamental amorphous and unified sensory experience, which later in phylogenesis becomes differentiated; and of Révész speculation that this embryonic primal modality might perhaps have been a tactile one.

Many of the questions which concern imagery turn largely upon the duration of the blindness. Visual impressions are dominant in the realm of the senses and they are not easily forgotten. The shorter the history of blindness, or to put it another way, the later the age at which the subject lost his eyesight, the more established is the rôle of visual associations.

The importance of tactile thinking in the blind becomes obvious in so far as their body-image is concerned. Ordinarily, this is a conception which is slowly built up from an interplay of visual, tactile, vestibular and proprioceptive afferents, to which are added various processes of abstraction and identification. Of all these, vision is by far the most important, for it both affords knowledge as to the appearance of one's own body, and permits comparison with that of others. The body-image of those born without sight must therefore be quite unusual. This idea can be confirmed by a study of the graphic and plastic art of the blind, especially when the human form is depicted. Bodily parts which for the moment assume especial importance are generally exaggerated. The hands and fingers are often of excessive size, as mirroring the dominant part played by the organs of touch in the blind person's body-image. In von Stockert's experience, congenitally blind children model a head with a disproportion in size and arrangement of the component parts. The region of the mouth is usually the most conspicuous feature, while the ears or eyes may be omitted. This is not surprising in view of the importance of the sensitive lips and constantly moving tip of the tongue:

and the rôle of the mouth in breathing, feeding and talking. Bakwin noticed that his blind pupils would model in such a way that the head would be too large and too full of detail. Münz and also Löwenfeld have made observations on this subject. They have rightly criticized the rather narrow conception of the art of the blind expressed by Voss, Burde, Matz and others. In their opinion, a vital creative process springs from bodily sensations, and these factors which are more likely to produce distorted models than a mere defect of visual controls. A blind person's drawings or sculpture show an enhancement of parts of the body which are emotionally emphasized. The relative size and proportion of components are determined by "value judgments" and by their emotional significance to the artist rather than by morphological rectitude. This is particularly so when the creative work is based upon autoplastic experience; that is, founded upon the recollection of an affectively tinged experience.

Haptic space.—A psychological study of the blind confirms that tactile phenomena contribute to spatial perception and also to the subject's idea or notion of surrounding space. This is also the case in normal-sighted individuals, but much more so in the blind. Révész made a distinction between "optohaptics" (which is the touch world of sighted individuals), and "pure haptics" as experienced by the blind. Blind persons are conscious of a space world which is smaller than in the case of those who can visually sweep the distant view and relate objects in the environment one with another, and with themselves. The blind cannot gain a knowledge of large objects, especially at a distance—e.g. a building, a mountain—for they need to pass their exploring hands over the contours of an object in a laborious fashion in order to be informed. Touch is, however, superior to vision in so far as the solid properties of small objects can be quickly realized by the examining hand. Galton, it is true, said that a few normal persons are endowed with a sort of "tactile sight," which allows them to visualize the appearance of surfaces of things which are actually out of view. This is why people who have been blind for many years develop a three-dimensional tactual imagery for objects which are small enough to be "feelable," while larger objects are conceived of in vague visual two-dimensional qualities. Heller distinguished a "narrow" from an "enlarged" tactile sphere in the case of the blind. Villey has spoken of *manual* space, *brachial* space and *ambulatory* space, as making up the spatial notions of the blind. The first two are largely aspects of the body-image, and hence belong to the domain of personal space. The hands serve as linkages or outposts connecting personal with extrapersonal space. Beyond ambulatory space, which represents the range of a few paces only, lies the "touch horizon" which delimits remote space, of which

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the blind person has but a hazy conception. For orientation within this remote space, he largely relies upon acoustic stimuli which, as they vary in intensity, may bring about considerable deceptions. Thus, a quiet sound may evoke an idea of distance, while the same sound, but louder in intensity, may give the illusion of being nearer. This remote space is void and mysterious and only comes alive by dint of diverse but meaningful sounds. Blind persons dislike an environment of absolute silence, which makes them uneasy and unsure.

Rather less satisfying is Birkmayer's classification of the organization of space into concentric "space-shells" (Raumschalen). The innermost of these comprises the subject's own body; beyond comes the area of his grasp, and beyond that the outermost shell . . . the area of vision. Within each space-shell, the subject commands different measures of freedom, and is also liable to different patterns of disorientation.

Révész divided space into three extensions, viz.: (1) body space and empty space; (2) kinæsthetic and dynamic space; and (3) haptic and static space. He believed that blind persons have little, if any, tendency to think of space in terms of shape as many sighted people do, who may imagine an elliptically based cone or a parabaloid with themselves at the apex; or, more rarely, a sphere with themselves in the centre. The blind are probably not deeply interested with abstract, mathematical or philosophical ideas of space, but rather with the simplest possible concrete geometric relationship between one tactually perceived external object and another. They are not much concerned with the ordinary cardinal directions within their haptic space, and for them a conception of accurate horizontal or vertical orientation is not important. Movement, on the part of the blind person, alters radically the idea of the emptiness of space. An even more vivid change occurs when an external object is touched. Immediately, there is a breakdown in the passive feeling of one-ness with space; the "ego-like character of being a mere point in space."

Particularly in the vertical dimension are the blind person's spatial ideas defective. Accurate conceptions of height are difficult for them, unless the object happens to lie within the range of their examining hand. Space is for them a much more compressed environment, for they cannot direct their gaze upon the surrounding panorama and divert their attention from one distant object to another. Things that they can hold and examine within the compass of their hand evoke a pseudo-visual image, but often a relatively small one. Larger objects which have to be felt by dint of wide angle arm movements give rise to a less vivid imagery, and here too the impression is one of smallness.

The spatial difficulties of a congenitally blind person include a number

of notions which, being ordinarily pure visual phenomena, are not easy to achieve. For example, it requires a certain intellectual effort to understand what sighted people mean by perspective, and the notion can be taught only by way of a tactile analogy. The idea of a reflection in a mirror is yet another phenomenon almost as hard to explain to a blind person as that of colour.

Few cases of successful post-operative acquisition of sight by those born blind have been fully studied from a neuro-psychological angle. We know enough, however, from the work of von Senden and others, to be able to say that illusory spatial distortions are considerable, even though they are usually temporary. Objects may appear unexpectedly large to the newly opened eyes, as well as unduly close—almost indeed touching the face. Some objects cannot be recognized at first, and there is especial

TRACE OF MOVING FINGER.

'PROVE BENEFICIAL TO DR. HEWLETT JOHNSON' (BRAILLE TRANSLATION)

FIG. 1.—Tracing of the touch-movements of the left index finger, of a male patient of 31 years, blind since the age of 5. He is reading the braille symbols depicted, and is slowed up when the finger reaches the rather unexpected term "Dr. Hewlett." The circumductory movements of exploration are well shown, but there is no record of the speed of the tracing nor of the varying degrees of pressure exerted by the reading finger. The patient was a particularly skilled and rapid braillist, who always used the left hand for reading.

BOOK EMBOSSED IN GRADE

FIG. 2.—The touch-movements of a normal-sighted person who is not a braille reader, but who has memorized the visual form of the punctographic alphabet. Large braille type is used. There is no record of the varying pressures, nor of the very many errors made in trying to identify each symbol in turn. The time taken to read this line was from two to three minutes.

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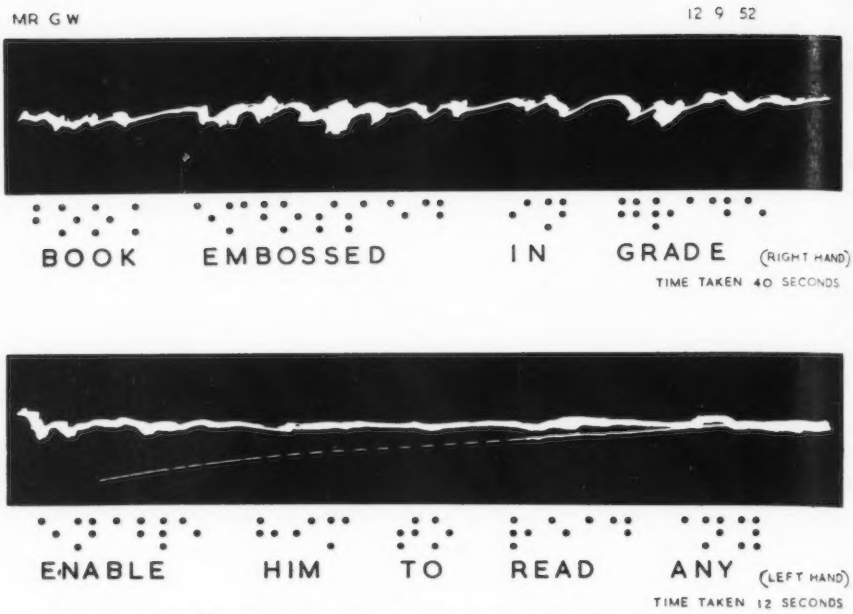

FIG. 3. – Touch movements carried out by a blind male of 45 years who lost his sight at 7 years. He is not a particularly rapid or skilled braillist. Large braille type is used. The lower line shows the smooth easy flow when the left, i.e. the "preferred" forefinger is used for reading. The upper line shows the touch movements which appear when the right or unaccustomed forefinger is used. Reading with his left forefinger is quicker, the line being read in 12 seconds (below) as opposed to 40 seconds (above).

difficulty in distinguishing two from three-dimensional objects. Human faces and figures cannot at first be identified by sight alone. The early days of this convalescence are uneasy and exhausting. With the acquisition of a new weapon of experience, the older tools seem to become blunted. Acuity of hearing seems to diminish and manual dexterity to deteriorate remarkably. The promise of the gift of vision is not altogether a pleasurable one, and indeed, is often evaded or resisted. Diderot spoke of one congenitally blind man who said he would prefer God to furnish him with especially elongated arms rather than functioning eyes. ("Si la curiosité ne me dominoit pas," dit-il, "j'amerois bien autant avoir de longs bras: il me semble que mes mains m'instruiroient mieux de ce qui se passe dans la lune que vos yeux ou vos télescopes; et puis les yeux cessent plûtot de voir, que les mains de toucher. Il vaudroit donc bien autant qu'on perfectionnât en moi l'organe que j'ai, que de m'accorder celui qui me manque.")

Neurologists would do well therefore to turn to blind individuals in

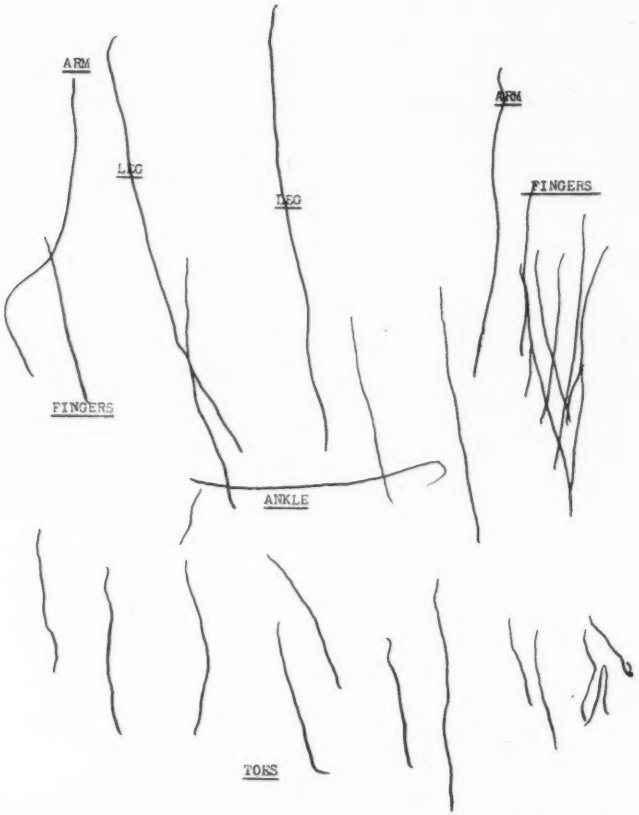

FIG. 4. – The patient, blind since the age of 5 years, is asked to draw a man. Head, face and body are omitted altogether, while the fingers and toes receive undue emphasis. (Case No. 32125.)

their study of problems of spatial orientation, and of the mechanism of learning. They would find much to interest them in those born blind, as well as those who have lost their eyesight at a later age: in those who are afflicted with blindness coupled with deaf-mutism: in blind subjects who have gained the sense of vision after surgery; in blind adults who have developed an intercurrent focal disease of the brain, especially of the parietal lobe: in blind persons who have become aphasic, apraxic or agnosic: in those who have lost acquired tactile accomplishments and sense of obstacles as the result of diffuse cerebral injury or disease. All these raise problems belonging to territories where a neurologist has scarcely ventured and yet the clinical field promises to be rewarding.

The neurology of the blind and the world of haptics: the human hand as the instrument of touch: these are chapters for the future, even though Féré showed the way sixty years ago: *"The hand,"* he wrote, *"merits the notice of physiologists and psychologists who have up to now rather neglected it: for the hand is both an agent and an interpreter in the growth of the spirit."* ("La main est à la fois un agent et un interprète du développement de l'ésprit: elle mériterait d'arrêter davantage l'attention des physiologistes et des psychologues que l'ont un peu negligée.")

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NON-INFECTIVE INTRACRANIAL VENOUS THROMBOSIS

BY

H. J. M. BARNETT AND H. H. HYLAND[1]

SIR WILLIAM GOWERS (1888) recognized the existence of aseptic intracranial venous thrombosis. He and other physicians of his day considered it to be associated with marasmic and cachectic conditions and the result of a failing circulation. The next important observation on non-infective cases was by Holmes and Sargent (1915) who described the syndrome of post traumatic thrombosis of the superior longitudinal sinus. More recently, Martin and Sheehan (1941) have focused attention on the occurrence of intracranial venous and sinus thrombosis in the puerperium, a situation which was indeed mentioned in passing by Gowers (1888). Lhermitte (1936) has emphasized the association of this lesion with congenital heart disease in children and finally in the last few years a sprinkling of cases of apparently idiopathic type has been appearing in the literature.

Most of the observations in the literature have been on selected groups of patients which has led to ætiological theorizing of doubtful validity. Therefore it was thought worth while to study the proven cases at the Toronto General Hospital in order to ascertain the over-all incidence of non-infective intracranial venous thrombosis and the ætiological factors common to the cases. For this purpose we reviewed the 39 cases that had come to autopsy during the past twenty years. Table I shows the wide

TABLE I.—ASSOCIATED DISORDERS IN 39 FATAL CASES

Heart Disease	10
Cachexia and marasmus	7
Post-operative	5
Post-traumatic	5
Arterial occlusion or hæmorrhage	4
Post-partum	3
Blood dyscrasias	2
Fever therapy or hyperpyrexia	2
No associated disorder	1
Total	39

[1] From the Departments of Medicine and Neuropathology, University of Toronto and the Toronto General Hospital. Presented at the annual meeting of the Canadian Neurological Society, Banff, June 1952.

variety of circumstances under which the condition may occur and we will briefly describe some of the observations that emerged from the study of these various groups of cases.

TABLE II.—INTRACRANIAL VENOUS THROMBOSIS WITH HEART DISEASE

Type	*Intracranial*	*Significance*
* Atherosclerotic	S.L.S.	Major
Atherosclerotic	Venous	Major
† Atherosclerotic	Venous	Contributory
Atherosclerotic	Venous	Terminal
Atherosclerotic	Venous	Terminal
Hypertensive	Venous	Contributory
Aortitis	Venous	Contributory
Rheumatic	S.L.S. + Ven.	Major
Congenital	Venous	Contributory
Pulmonary	Venous	Terminal

* Arterial occlusion also present.

† No failure.

Heart disease.—This group (Table II) was the largest of all, which was surprising since previous observations have been concerned with its occurrence in children with congenital heart disease (Lhermitte, 1936; Hunter and Lipscomb, 1942). In this material all the common forms of myocardial and valvular disease are represented. The common factor, with one exception, was the presence of right heart failure, usually of severe degree or rapid onset. The exception developed his neurological symptoms during 2 successive episodes of coronary insufficiency with accompanying marked drop in blood pressure.

The importance of this intracranial complication relative to the heart disease varied from case to case. In 3 out of the 10 patients it was of major importance and the chief and immediate cause of death. In 4 it was thought to be a contributory cause of the fatal outcome and in the 3 remaining it was judged to be merely an unimportant terminal episode. Clinically the manifestations accompanying these lesions will often be considered due to cerebral emboli unless the possibility of venous thrombosis is kept in mind.

In only 2 cases was the superior longitudinal sinus involved and for the most part the thrombosis was confined to the superficial or deep cerebral veins, or both as seen in fig. 1. The infarctions were hæmorrhagic and necrotic in all instances. In the rheumatic case there was such extensive superficial hæmorrhage that it led to the clinical diagnosis of subarachnoid hæmorrhage from a ruptured berry aneurysm coexisting with the heart disease. Since anticoagulant therapy, in cases of cerebral arterial occlusion associated with heart disease, may lead to hæmorrhage

FIG. 1.—Hæmorrhagic infarction in distribution both of deep cerebral and superficial cortical veins in 61-year-old patient with cardiac failure from arteriosclerotic heart disease.

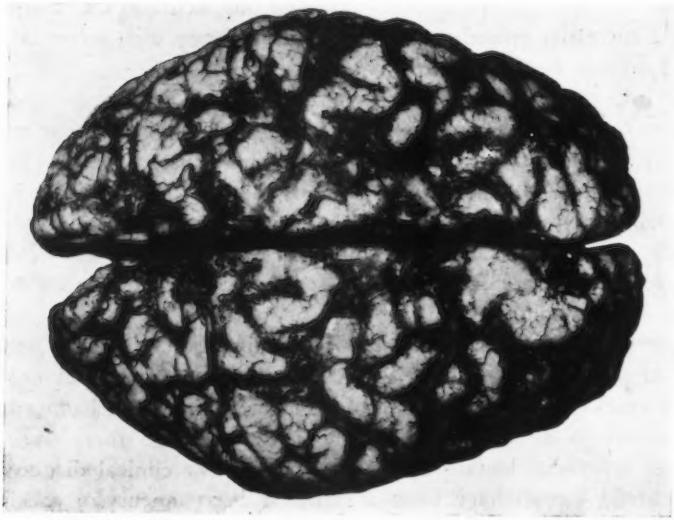

FIG. 2.—Brain of patient who suffered severe asthma for twenty years showing marked varicosity and variable dilatation of cortical veins without thrombosis.

into initially non-hæmorrhagic infarctions it is evident from the marked hæmorrhagic nature of these lesions that venous occlusion provides an even greater contra-indication to this form of treatment.

We were interested to find that only one patient in this group had pulmonary heart disease because the interference with cerebral venous return that occurs in this condition might be expected to predispose to venous thrombosis. It was surprising also that no cases of long-standing asthma nor patients dying in status asthmaticus were found to have thrombosis of cerebral veins. Fig. 2 shows the extreme and variable dilatation and varicosity of cerebral veins in a long-standing asthmatic patient. The failure to find intracranial venous thrombosis in cases of this nature suggests that local factors are of less importance in causing the condition than are alterations in the coagulability of the blood.

Cachexia and marasmus.—The 7 cases in the cachectic group are of lesser interest and importance. 5 were patients with carcinomatosis, one was a neglected, dehydrated and emaciated mental defective, and the final patient had severe exfoliative dermatitis. Most of them demonstrated no neurological signs and the thromboses were terminal without accompanying recognizable cerebral softening. The longitudinal sinus was occluded only once in this group, the remainder having the thrombosis confined to the cortical veins.

Post-operative.—Excluding craniotomies and states of post-operative sepsis and cachexia, there are no previous reports of proven thrombosis of the cerebral veins and sinuses after operation. This is curious since we found 5 such cases amongst the autopsy material as shown in Table III.

TABLE III.—INTRACRANIAL VENOUS THROMBOSIS OCCURRING POST-OPERATIVELY

Case	*Operation*	*Time of onset*	*Mode of onset*	*Other post-operative complications*
1	Hysterectomy	4 days	Gradual	Nil
2	Cholecystomy appendectomy	8 days	Gradual	Nil
3	Thyroidectomy (2 stage)	6 weeks	Sudden	Thyroid storm (stage 1) crural phlebitis
4	Blalock for tetralogy of Fallot	7 days	Sudden	Hæmothorax, Int. carotid thrombosis
5	Gastro-enterostomy	24 hours	Gradual	Massive G.I. hæmorrhage

In these cases the intracranial lesion was the cause of death in all but Case 5. In Case 4 where the superior longitudinal sinus and cortical veins were thrombosed it was not possible to say which came first, the arterial or the venous thrombosis, but it was evident that the venous lesion was of most importance in this patient's death since the least œdematous of the

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hemispheres corresponded to the side on which the carotid artery was thrombosed (fig. 3).

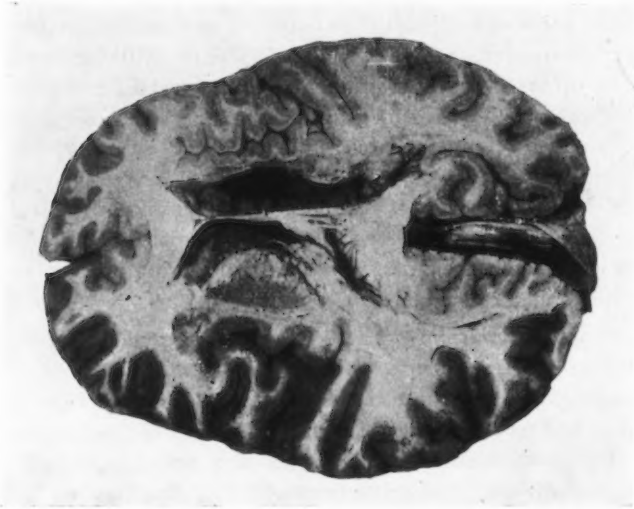

FIG. 3.—Post-operative death following Blalock operation. The internal carotid artery supplying the least swollen of these hemispheres was thrombosed. Thrombosis of the overlying cortical veins in conjunction with thrombosis of the superior longitudinal sinus led to the extensive œdema of the other hemisphere.

It will be noted that the onset was gradual in 3 cases. One patient (Case 2) with intermittent symptoms showed pre-mortem thrombi of varying ages in the cortical veins corresponding to the clinical episodes. These factors are in keeping with our belief that the process is one of thrombosis in situ. In a histological study of venous thrombosis in calf veins evidence of recurrent thrombosis was found in 54 per cent (Raeburn, 1951). Even in the 2 cases designated as having a sudden onset the initial process may have been gradual although *grand mal* seizures were the first manifestation.

In 2 instances a dural sinus was thrombosed. In the others the thrombosis was confined to the superficial veins. This is contrary to Courville's claim (1945) that without a local pathological process thrombosis does not occur in cerebral veins unless secondary to sinus thrombosis. In all cases the infarcted area was hæmorrhagic, necrotic and associated with considerable adjacent and generalized œdema. In one instance there had been fairly massive hæmorrhage into the infarctions and there was subarachnoid hæmorrhage as well as intraventricular spread of this hæmorrhage.

Post-traumatic.—Apart from the work on traumatic thrombosis of the superior longitudinal sinus done by Holmes and Sargent (1915) in World War I, by Barker (1949) in World War II and the observations of Martin (1944) in 2 closed head injuries, little consideration has been given to the importance of vein and sinus thrombosis in traumatic cases. Table IV shows the 5 cases with significant venous or sinus thrombosis after trauma in this series. In 3 instances it was associated with other severe widespread brain and vessel damage, so that at first glance it might be thought to be of little significance. In Case 3, however, there was severe traumatic disruption confined to one temporal lobe, as shown in fig. 4. Unfortunately

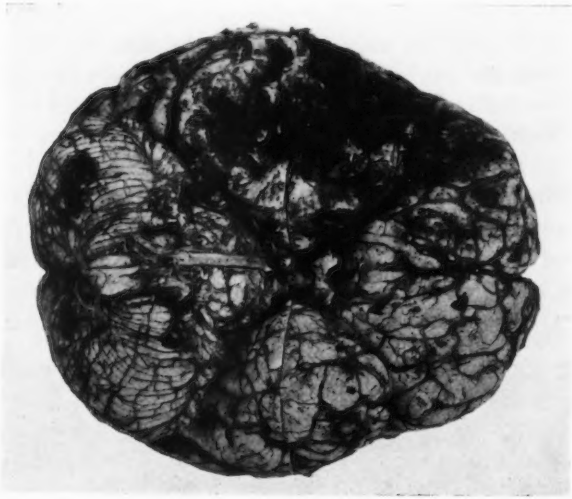

FIG. 4.—Brain showing "traumatic disruption of the temporal lobe." A large vein over this pulped cortex was thrombosed but is not clearly shown against this hæmorrhagic background.

the large vein filled with thrombus does not show well in this photograph but at autopsy it was clearly seen in the subarachnoid space overlying the grossly hæmorrhagic area. It is suggested that venous thrombosis should be carefully looked for at autopsy in all these traumatic cases with "pulped brain" because the gross appearance with hæmorrhagic destruction extending deeply into the cerebral substance leads us to believe that venous thrombosis may be a contributing factor. Post-traumatic lesions of this type are usually attributed entirely to contre-coup or sheering forces and to the noxious effect of blood from ruptured vessels producing extensive local and generalized œdema.

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TABLE IV.—POST-TRAUMATIC INTRACRANIAL VENOUS THROMBOSIS

Case	*Thrombosis*	*Importance*	*Other damage*
1	Lateral sinus	Contributory +	Extradural hæmorrhage cortical laceration
2	Sup. long. sinus	Contributory +	Extradural hæmorrhage cortical laceration
3	Temporal veins	Contributory + +	Temporal lobe disruption
4	Sup. long. sinus + infarction	Major + + +	Extradural hæmorrhage (small) cortical laceration (slight)
5	Sup. long. sinus + infarction	Major + + + +	Nil

In the other cases the main result of the trauma was the production of sagittal sinus and cortical vein thrombosis with accompanying hæmorrhagic brain softening. Case 5 is that of a 50-year-old woman who sustained a fall four weeks before death, receiving a fractured humerus and a bump on the head that was considered trivial. Three weeks afterwards she began to complain of headache followed three days later by a rather sudden onset of hemiplegia; she then gradually slipped into a fatal coma. The necrotic and hæmorrhagic lesion in the hemisphere contralateral to the hemiplegia is well shown in fig. 5. Venous thrombi were also found in liver. lungs, femoral and saphenous veins. To us this seems a case of

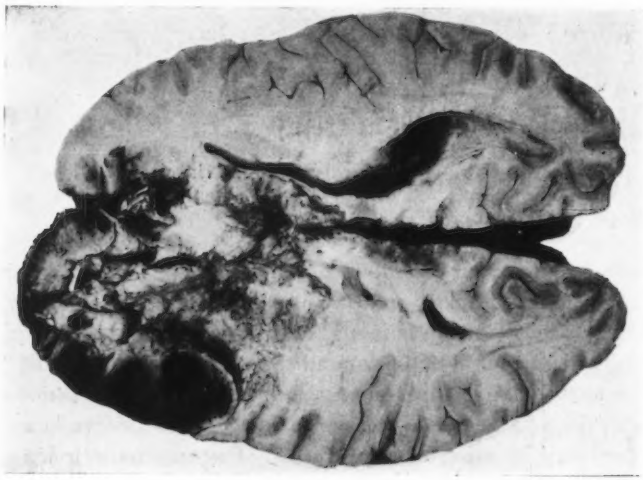

FIG. 5.—Necrotic and hæmorrhagic appearance of brain from patient who died one month after injuries received in a fall, the head trauma being trivial. Overlying veins were extensively thrombosed.

great importance in that it emphasizes the tendency of patients subjected to trauma to share the susceptibility of post-operative, post-partum and cardiac cases to venous thrombosis. We would suggest that the blow on the head three weeks before symptoms appeared merely determined the site of the intracranial lesion, but that the altered coagulability of the blood, probably brought about by the general trauma, was of greater significance.

With arterial occlusion or hæmorrhage.—Cerebral arterial lesions, usually occlusive, were occasionally found in association with intracranial venous thrombosis under the conditions previously mentioned. However we have collected a small group of cases with venous thrombosis in which no predisposing factors save cerebral arterial thrombosis (or in 1 case hæmorrhage) was apparent and in which we must presume that the arterial lesion preceded the venous occlusion (Table V). This group is of particular interest from a diagnostic viewpoint. We have recently studied a case, arteriographically proven to have a thrombosis of the internal carotid artery, in which prolonged papillœdema in association with normal ventricles led us to believe that he had sustained a concomitant thrombosis of his superior longitudinal sinus. This same sequence of events had occurred in Case 3 shown in Table V.

TABLE V.—INTRACRANIAL VENOUS THROMBOSIS ASSOCIATED WITH ARTERIAL LESIONS

Case	*Age*	*Arterial lesion*	*Venous occlusion*
1	63	Thrombosis post cerebral	Rolandic vein
2	68	Hypertensive Intraoccipital hæmorrhage	Sup. long. sinus
3	75	Thrombosis internal carotid	Sup. long. sinus
4	70	Softening distribution post. cerebral	Temporal veins

Two of these cases had a sufficiently severe reaction to the infarcted cortical tissue to have more than 1,000 polymorphs in their cerebrospinal fluid. In these circumstances the diagnosis of meningitis had to be seriously considered but the presence of xanthochromia and an equal or even greater number of red cells suggested a vascular lesion.

Post-partum.—In this twenty-year period there have been only 3 post-partum cases coming to post-mortem. The clinical picture in all 3 patients included varying degrees of paralysis and sensory loss. The development of the illness nevertheless tended to be insidious. In 1 there was a two-day prodromal period of headache followed by unconsciousness and in another case personality change and generalized fatigue developed five days before the onset of seizures. The third patient had premonitory headache and

mental dullness for twenty-four hours. This insidious onset is emphasized as we regard it as good evidence against the suggestion that these cases are of embolic origin.

One case, reported elsewhere (Hyland, 1950), is of unusual interest because the clinical manifestations cleared up almost completely over a period of ten days but four days later she died suddenly with massive pulmonary embolism. Examination of the brain showed extensive cortical venous thrombosis with cortical softening and hæmorrhage most marked in the left frontal lobe (fig. 6). There was considerable œdema still evident

FIG. 6.—Vertical section through frontal lobe of patient clinically recovering rapidly from post-partum cerebral venous thrombosis and dying of pulmonary embolism. The softening and hæmorrhage is involving mainly the cortex, the deep white matter being relatively spared. (Reproduced by courtesy *Journ. Am. Med. Assoc.*, Chicago.)

but early recanalization of the superior longitudinal sinus was seen on section.

Another patient was initially considered to have had spontaneous subarachnoid hæmorrhage due to a ruptured berry aneurysm because lumbar tap had yielded grossly bloody cerebrospinal fluid. Extensive hæmorrhagic destruction of cortical and subcortical tissue with spread to the subarachnoid space was found. The subarachnoid hæmorrhage over the hemispheres and the hæmorrhage in the substance of the brain in this case are shown in figs. 7 and 8.

Blood dyscrasias.—Despite a large hæmatological service at the Toronto General Hospital, we have encountered only 2 patients with cortical vein or sinus thrombosis in fatal cases of blood diseases. In one, a case of myeloid leukæmia, the superior longitudinal sinus and the lateral sinus were occluded. In the other, a case of polycythemia rubra vera, there

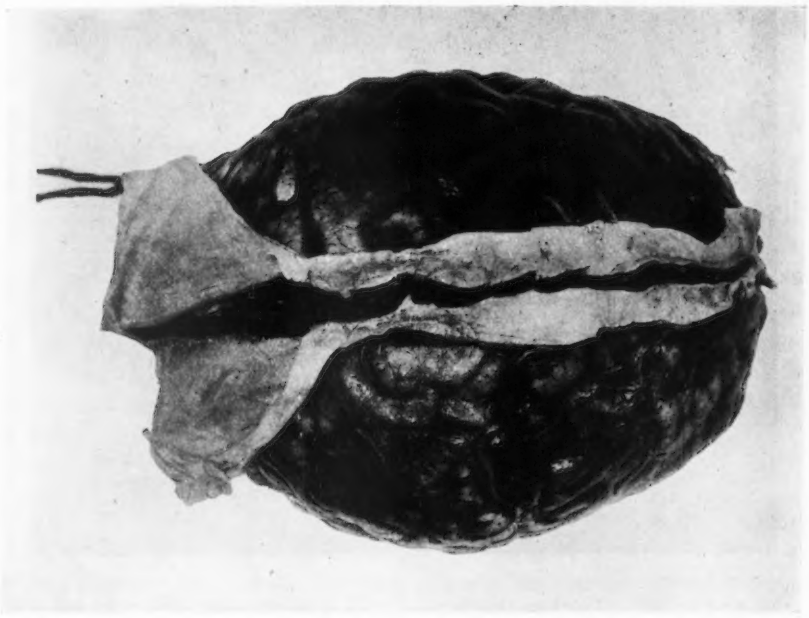

FIG. 7.—Extensive subarachnoid hæmorrhage in association with longitudinal sinus and cortical venous thrombosis is seen in a patient who died post-partum with a clinical picture of subarachnoid hæmorrhage.

was a combination of deep cerebral vein thrombosis and thrombosis of one posterior cerebral artery.

Although cases with post-mortem verification are so scarce, we suspect that occasional patients with chronic leukæmia whose ventricles are normal, and who yet have severe papillœdema and increased intracranial pressure, may also be suffering from superior longitudinal sinus thrombosis.

Fever therapy and hyperpyrexia.—There are 3 cases in our records who died within a few minutes of cessation of therapy for syphilis in the fever cabinet. 2 of them had evidence of generalized arterial and venous thrombosis elsewhere than in the brain but 1 showed this combination intracranially. This was of interest to us since it was comparable to what was found in a 21-year-old man from the Toronto Psychiatric Hospital. He had been admitted there in acute mania and had died in a state of hyperpyrexia. The striking finding was the extreme congestion of all cerebral veins with thrombosis of a number in the frontal region that was judged to have occurred several days before death.

It must be emphasized that all patients who die in acute mania with

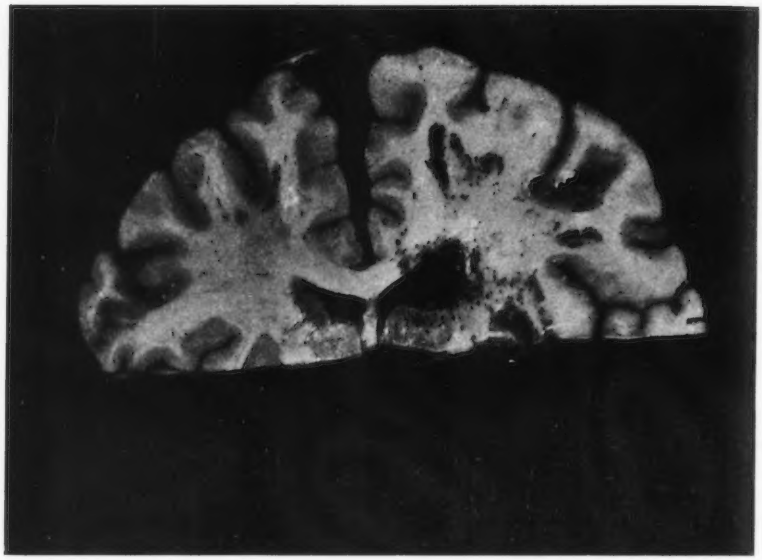

FIG. 8.—Coronal section of hemispheres from same case as fig. 7 showing extensive hæmorrhage infarction of superficial and deep structures. The thrombosed superior longitudinal sinus can be seen.

hyperpyrexia do not show cerebral venous thrombosis. It is suggested, however, that when such patients recover and have sequelæ the possibility of this lesion should receive consideration.

Without associated disorder.—We have one case in which the intracranial venous thrombosis could not be related to any constitutional disorder or other factor such as has been considered previously. This case was somewhat analogous to what has been called "toxic hydrocephalus" or "pseudo tumor cerebri" except that it lacked the gradual onset and evidence of increased intracranial pressure seen in this uncommon clinical syndrome.

The patient, aged 55, was stated to have been subject to attacks with loss of consciousness. He was found lying unconscious on the floor and died three days later without regaining consciousness. The brain showed diffuse recent subarachnoid hæmorrhage over both hemispheres originating from areas of softening in both frontal lobes with massive hæmorrhage into the cortex and subcortical white matter. The superior sagittal sinus was not occluded but on section of the dura in this region there were old organized and also recent localized thrombi found in the lateral venous lacunæ which had evidently caused obstruction to venous drainage with

bilateral softening and massive hæmorrhage at the vertex in the frontal lobes.

There have been a few cases similar to this reported, in which non-infective cerebral venous thrombosis has been found at autopsy with no apparent cause or associated disease being evident (Irish, 1938; Silbermann, 1951; Smith, 1952).

Comment

Ætiology.—Non-infective venous thrombosis is much less common intracranially than elsewhere in the body. However the observations presented indicate that intracranial venous thrombosis occurs in the same types of cases and in about the same relative proportion of these to one another as does thrombosis in the veins of the limbs or pelvis. Table VI shows the relative incidence of other thrombo-embolic phenomena in this series of cases of intracranial venous thrombosis. It will be noted that almost half of the 38 cases had evidence of thrombosis or embolism elsewhere.

It appears, therefore, that the problem of ætiology of intracranial venous thrombosis is similar to that of thrombosis in veins anywhere because they occur under similar circumstances. Thus it is unnecessary to invoke special mechanisms for its development such as have been suggested in puerperal cases, namely air embolism, embolism by way of the paravertebral venous plexuses, damage to vein walls due to engorgement during pregnancy, etc.

Table VI.—Relative Incidence of Extracranial to Intracranial Venous Thrombosis

	Intracranial thrombosis	*Other thrombo-emboli*
Cardiac group	10	8
Post-partum	3	3
Others	25	7
Total	38	18

After pointing out the similarity of circumstances that may lead to the occurrence of intracranial and extracranial venous thrombosis we can take the ætiology no further. It is still impossible to predict with accuracy from any laboratory tests which individual patient is likely to develop venous thrombosis. A knowledge of the type of case that might develop this complication is the only guide and we believe that no distinction can be drawn between the liability for femoral vein thrombosis or for thrombosis of intracranial veins and sinuses.

Subarachnoid bleeding.—The cerebral lesion is characteristically one of hæmorrhagic necrosis, either superficial or deep or both, in all the

ætiological groups that we have discussed. When the cortex is severely involved massive subarachnoid hæmorrhage may be associated which can lead to a wrong diagnosis of ruptured berry aneurysm such as occurred in one of our post-partum cases and one case of cardiac failure. Well-marked subarachnoid hæmorrhage was found also in several others including the delayed traumatic case, the idiopathic case and one post-operative case.

Because of the hæmorrhagic nature of the infarctions found in this condition we again want to emphasize the great danger in the use of anticoagulant therapy which has been advocated by most recent writers on this subject (Martin, 1941; Kendall, 1948; Ray and Dunbar, 1950; Silbermann, 1951).

Prognosis.—We have referred previously to a post-partum patient with extremely severe cortical venous thrombosis who made a rapid and almost complete clinical recovery only to die of pulmonary embolism. The observations in this case suggest that if additional morbid factors do not exist to contribute to or to cause a fatal outcome many patients with intracranial venous thrombosis are capable of recovery. Most of the patients in this series had contributory and sometimes more major causes for their deaths. However the condition may occur in otherwise healthy individuals and we have a growing group of post-partum and "pseudo-tumour" cases under observation who have recovered from the effects of the intracranial lesion. While some of the patients with the "pseudo-tumour" syndrome may not have sinus or venous thrombosis, probably this lesion is present in the majority. The relationship of sinus thrombosis to the "pseudo-tumour" syndrome has been demonstrated radiographically by Ray and Dunbar (1950) using a technique of sinography first utilized by Frenckner (1934, 1936).

While it appears that extensive damage to the cortex can occur without permanent residual signs, certain patients who recover have persistent disabilities such as hemiplegia. The determining factor seems to be not the extent to which the cortical veins are thrombosed but rather the extent of the damage to the subcortical white matter either by deep vein thrombosis or by extensive hæmorrhage following on the infarction. The localized area of cortical damage seen in fig. 6 would be less likely to cause permanent residual signs than would that shown in fig. 8 where the infarcted areas include the deeper tissues. Occasionally epilepsy is observed beginning in the post-partum or post-operative period and we have seen epilepsy follow an attack of otitis media and persist, with a temporal lobe focus in the electroencephalogram. Intracranial venous thrombosis should always be considered in the diagnosis of such cases since mild degrees of this con-

dition, leading to healed cortical scarring, may be more common than is fully appreciated at the present time.

ACKNOWLEDGMENT

We wish to express our thanks to Professor E. A. Linell for allowing us full access to his autopsy records.

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A STUDY OF THALAMIC AND CORTICAL RHYTHMS IN *PETIT MAL*[1]

BY

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SOME features of the electroencephalographic discharges in *petit mal* attacks have suggested that they might have an origin deep in the substance of the hemispheres. In many instances the wave-and-spike complexes of *petit mal* occur simultaneously all over the scalp; the discharges are usually bilaterally symmetrical and synchronous; and no focus of origin may be found in the electroencephalogram. Although it has seemed reasonable to look away from the cortex for the origin of the rhythmic wave-and-spike disturbances, a simple subcortical source of the discharges cannot explain all their features. Why should the rhythms be synchronous in all areas, and why should there be absence of signs of spread?

The wave-and-spike discharges of *petit mal* have been discussed in this way, with the idea of a possible deep "pace maker," by Jasper and Fortuyn (1947), and indirect evidence from animal experiment has been offered to show that deep structures are concerned in the attack. In 1940 Lewy and Gammon recorded wave-and-spike discharges from a cat's cortex after the thalamus had been stimulated. This wave-and-spike discharge sustained itself, as in human *petit mal*, after the stimulus had ceased. Then Morison and Dempsey while describing their important observations on the cortical effects of thalamic stimulation in cats from 1941 to 1943, showed that rhythmic discharges with features similar to those of *petit mal* could be evoked by rhythmic stimulation of the intralaminar region of the thalamus at 3-a-second. Hunter and Jasper (1949) have recently summarized these evidences that the thalamus may play a part in initiating and maintaining a 3-a-second wave-and-spike discharge in the cat. Jasper and Fortuyn (1947) repeated Dempsey and Morison's earlier work and recorded this rhythmic discharge from the cat's cortex on stimulation of the intralaminar part of the thalamus, so that Hunter and Jasper (1949) then observed the cat's behaviour during similar stimulation. They produced an "arrest reaction," in which the animals remained immobile during stimulation, a

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response similar to the state of "adynamia" produced in cats by Hess (1949) when he was stimulating in the same area. There is thus an increasing body of evidence that clinical and electroencephalographic disturbances, similar to those seen in human *petit mal,* can be produced in cats on repetitive stimulation of the intralaminar region of the thalamus.

After Lewy and Gammon's original observation it seemed interesting to record from the thalamus and other structures in children with *petit mal,* and the method used has been fully described (Williams and Parsons-Smith, 1949). Since 1946 six children have been studied because they were cooperative; they had sufficiently frequent *petit mal* attacks; the electroencephalogram showed typical rhythmic 3-a-second wave-and-spike discharges; and they had previously had a ventriculogram. Such suitable cases are very uncommon especially as patients with juvenile *petit mal* rarely need a ventriculogram as part of their routine investigations. In this paper some of the results are recorded. I am grateful to Dr. Gerald Parsons-Smith for his help in obtaining the records.

Results

Fig. 1 shows a *petit mal* attack in Case K. C., a girl of 9. The positions of the electrodes in the hemispheres are shown in figs. 2 and 3. The 5 needle electrodes are 2 cm. apart, and the terminal two are within the thalamus, that at the needle's tip being deep in the ventrolateral part, and

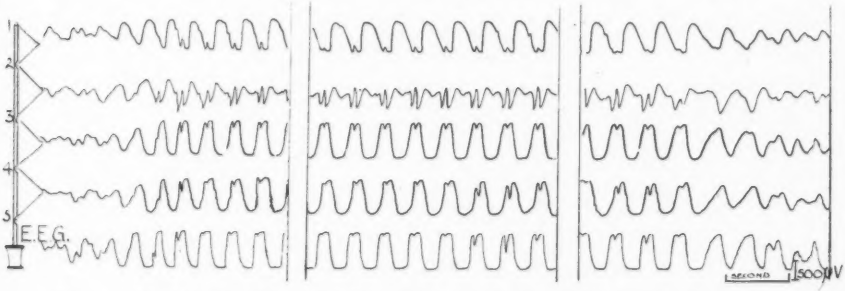
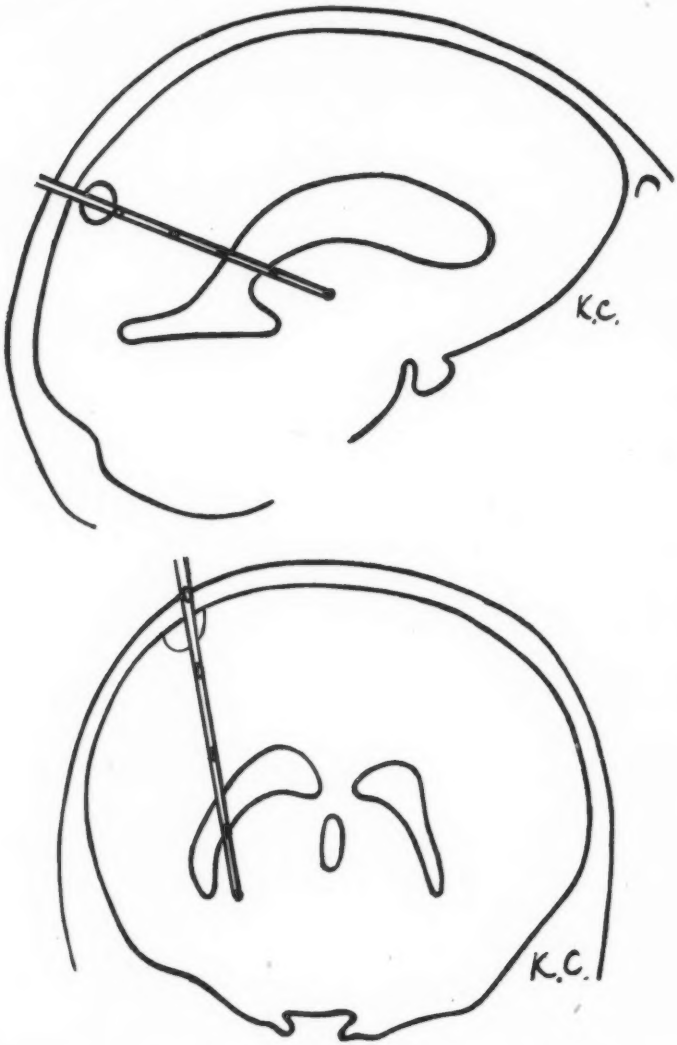


Fig. 1.—In this and the succeeding records a brain needle containing five electrodes is shown diagrammatically on the left, with the four electrograms recorded from each of its neighbouring pairs of electrodes, each 2 cm. apart. The electrode at the needle tip is in the thalamus, the one at the hilt near the scalp. The lowest tracing is an electro-encephalogram record made from fronto-parietal scalp electrodes. Gaps in the record indicate parts of a long *petit mal* attack removed from the figure for convenience. These records are fully described in the text. Note the onset of the attack with 3-a-second waves, out of phase in the upper two traces, the appearance of a spike in all traces, then a constant phase reversal between traces 2 and 3, the wave in trace 2 becoming biphasic. In the last section of the record the spike decrements in trace 2 and then the wave dies away. All the figures are described in the text.

the second in or near the postero-ventrolateral nucleus just above the pulvinar, according to the topographical charts of Ajuriaguerra, Hecaen and Talairach (1950). The third electrode is in the subcortical white matter, the fourth near the deep surface of the cortex, and the fifth just



FIGS. 2 and 3.—Tracings of antero-posterior and lateral view of the ventricles of Case 1 superimposed on the shadow of the needle *in situ*. Parallax makes interpretation of the exact position of each electrode difficult in a single view.

inside the scalp. It must be remembered that the exact positions cannot be computed from a single picture because of the foreshortening and because of the curvature of the ventricles and cranium.

For the records in fig. 1 the amplification is only 10 per cent of the usual. Features that can be seen are the commencement of the attack with rhythmic waves which are out-of-phase in the top two traces, and in-phase in all the others; a spike then occurs in all traces and the 3-a-second sine wave becomes out-of-phase in the second and third trace. After this there is a constant repetition of spike-and-wave with little change. In the middle section of record the second top trace shows the wave in a biphasic form, showing that it is arising between electrodes 2 and 3. The end section shows the wave slowing to a little over 2-a-second, reduction in the size of the spike in the first two traces, its disappearance, and, after that, the slow decline of the rhythmic 2-a-second wave. The features seen in this *petit mal* attack will be enlarged upon in the subsequent figures.

In fig. 4 a *petit mal* attack similar to that in fig. 1 has started, and the

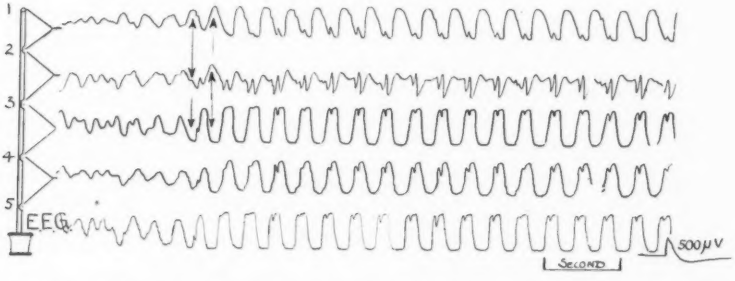


FIG. 4.—The arrows emphasize that there is a phase reversal in the initial waves, between traces 1 and 2, other traces being in phase. After a spike has occurred in all the traces, the wave phase reversal moves to traces 2 and 3 and the wave becomes biphasic in trace 2.

amplification is again only 10 per cent of that for standard recording. A rhythm of 3-a-second sine waves appears simultaneously in thalamus and cortex. There is, however, a phase reversal between the top two traces, all the others being in the same phase. This phase relationship is indicated by the direction of the arrows. The rhythm becomes more marked, then a spike appears in all leads. The next wave and all the subsequent waves are out-of-phase in the 2nd and 3rd traces, the wave being biphasic in the 2nd, indicating that it is arising from further up the needle than it did before the first spike occurred. The rhythm having become established, the relationship of the spike to the wave in the thalamus remains very constant.

In fig. 5 the amplification is ten times that in figs. 1 and 4. A rhythm of 3-a-second begins in the thalamus. It is out-of-phase in the first two traces as shown by the first arrows. At these arrows, about 2 seconds after

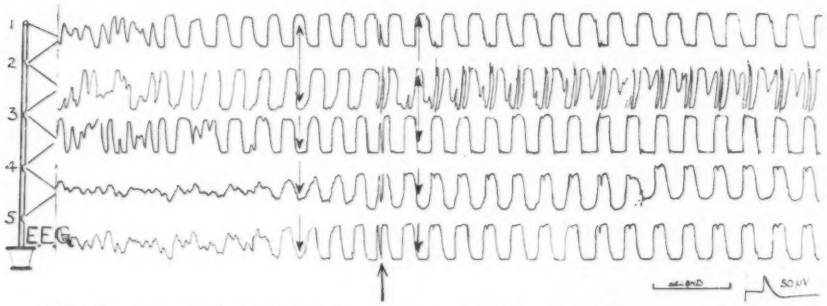


FIG. 5.—An attack begins with a 3-a-second rhythm, with reversed phase in traces 1 and 2, without any accompaniment in the cortex for the first two seconds. The rhythm becomes established in the cortex, and after a second a large spike appears in all traces. The phase reversal then moves to traces 2 and 3, as shown by the arrows, and the attack becomes established with spike-and-wave complexes.

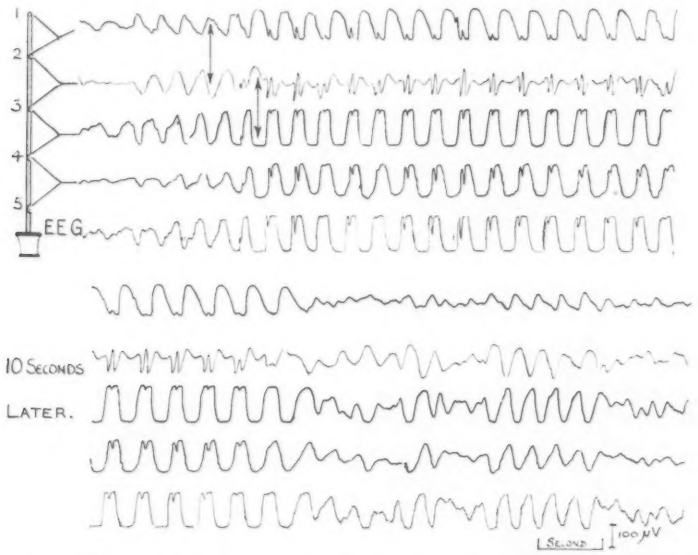


FIG. 6.—After a chain of events similar to those in the other figures, the frequency of the spike-and-wave complexes decreases so that after about 20 seconds there is visible slowing. The size of the spike in trace 2 then rapidly decreases and the attack ceases after the last spike has occurred. There is a recurrence of 3-a-second rhythms differing from the initial rhythm in that it is out of phase in traces 2 and 3. In these circumstances no spike develops and the rhythm dies down.

the rhythm has appeared in the thalamus, and has arisen within it, it begins to reach the cortex. It becomes more sustained in all leads. Then at the lower arrow the "*initial spike*" appears. This is not invariably the *first* spike, although it often is, but it is the first to appear in the electroencephalogram, cortex and the thalamus, together, showing that it has a wide propagation. This initial spike can be seen at the beginning of an attack in all the illustrations in this paper. After the initial spike the wave shows a phase reversal between traces 2 and 3, and becomes biphasic in trace 2. The rhythm is then established and continued.

Fig. 6, another attack in case K. C., again shows the 3-a-second rhythm which begins in the thalamus with its origin near electrode 2, reaches the cortex, becomes more sustained, then the "initial spike" occurs, the wave origin moves up the needle towards electrode 3, and a fully developed 3-a-second wave-and-spike attack occurs. Ten seconds of the attack are omitted. At the end of the attack the rhythm has progressively slowed to 2-a-second, then the spike, well seen in trace 2, decreases in size. After it ceases the rhythm dies out. In the last section the rhythm reappears, and *its frequency is again 3-a-second but now it arises at the third instead of the second electrode* as seen by the phase reversal remaining between traces 2 and 3. When this happens, no spike appears and the rhythm dies.

The course of events therefore appears to be that a 3-a-second rhythm arising deep in the thalamus increases in voltage and later appears in the cortex. It may take several seconds to do this, but the time varies. An initial spike then occurs which reaches all electrodes, in thalamus and cortex. This alters the site of origin of the wave in the thalamus. Subsequent spikes are followed by waves in an organized rhythmic way. The spike dies when the interval between successive spikes drops towards 2-a-second, and then the wave also ceases. When a 3-a-second wave reappears, unless it arises at the same point in the thalamus, a spike does not appear, and the rhythm dies.

In fig. 7 all the phenomena already described are seen, the paper speed being doubled.

(1) 3-a-second wave arising in the thalamus at electrode 2, and later appearing in the cortical leads.

(2) The "initial spike" followed by a change in site of origin of the 3-a-second wave.

(3) The regular 3-a-second rhythm slowing, followed by decrement and cessation of the spike and then the wave. The initial wave is very clearly seen at the vertical line. It can be seen to be out of phase between the 2nd and 3rd traces, its voltage being consistently much greater in trace 2.

indicating that it is arising from a point between electrodes 3 and 4, close to 4. From the ventriculogram in figs. 2 and 3, electrode 4 is in or near to the cerebral cortex.

The 3-a-second wave therefore arises in the central grey matter, in the

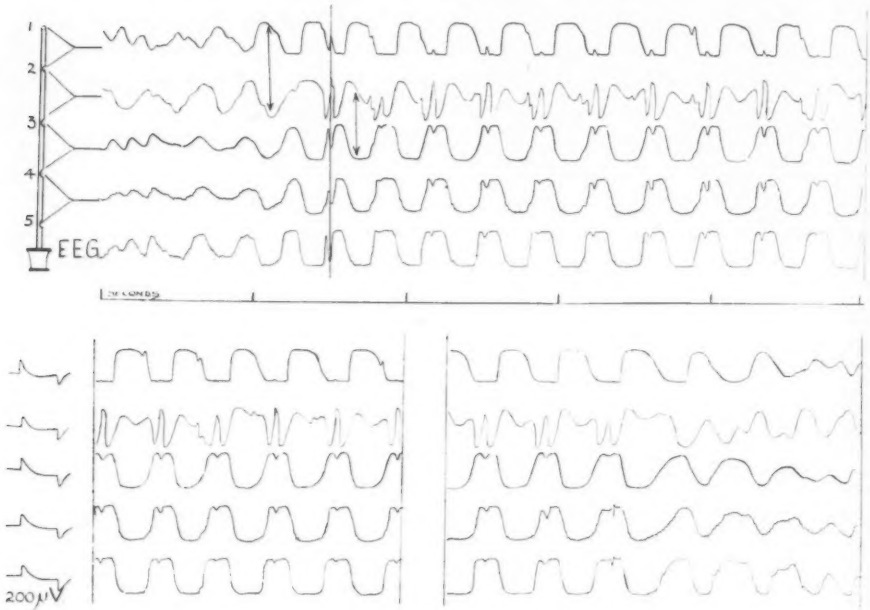


FIG. 7.—Similar to fig. 6, at double paper speed. The arrows indicate phase reversals. There is a phase reversal for the spike and the wave between traces 2 and 3 after the initial spike has appeared. The spike decays in the last section of the records, after slowing of the complex has occurred, and then the wave disappears.

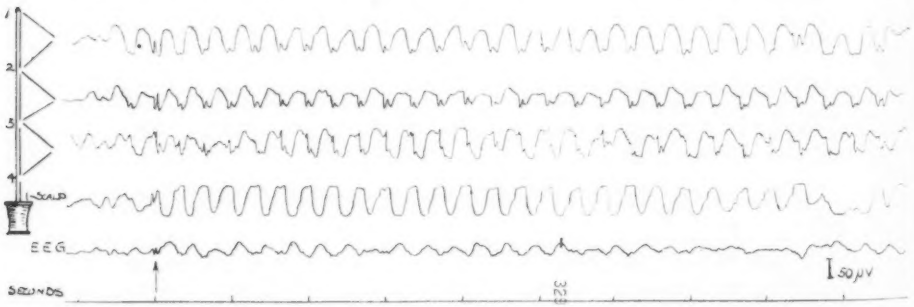
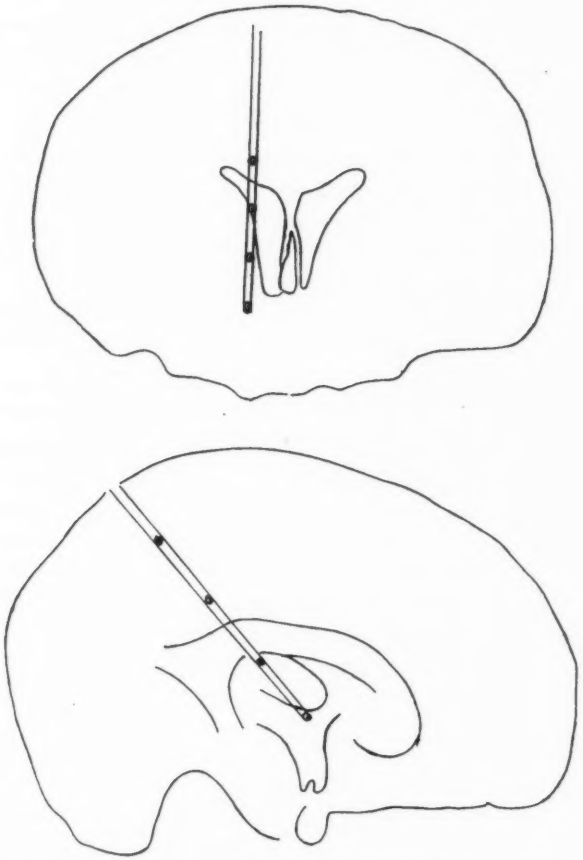


FIG. 8.—A typical attack from Case 2. The arrow points to the initial spike. Notice the impurity in the bipolar recording from the scalp compared with those from deep leads.

thalamus. When it becomes established a spike arises deep in the cortex which modifies the origin of the thalamic wave so that it becomes more superficial. The cortical spike continues to precede the wave and appears to be essential for the continuity of the 3-a-second rhythm. When the rhythm slows the spike decreases in voltage and ceases. This leads to cessation of the attack.

In interpreting the results so far, the origin of waves has been recognized by means of phase reversals. Although this method is a very reliable one, it simply indicates the *plane* of origin of a potential change, for reversal



FIGS. 9 and 10.—Tracings of antero-posterior and lateral views of the ventricles of Case 2 with the needle shadow superimposed.

about an electrode only means that that electrode is closest to the plane in which the point of origin lies. Records from another case will now be used to follow the spread of potential changes from electrode to electrode.

Fig. 8 shows a typical *petit mal* attack from Case C. B., a boy aged 4 with idiopathic *petit mal*. The records are made with a needle carrying only 4 electrodes. They are situated in the brain as in figs. 9 and 10. Study of all the projections shows that the distal two electrodes are in the thalamus, electrode 3 in the white matter and electrode 4 is deep in the cortex in the posterior parietal region. Comparison of the lateral views shows that the needle is introduced to the same depth as in Case K. C. but all the electrodes are about 1 cm. more rostral.

The antero-posterior view shows that both thalamic electrodes are in the medial region of the thalamus. Topographical measurement shows that the tip (electrode 1) is in the intralaminar structure in the mesial thalamus; electrode 2 is postero-mesial.

In fig. 8 the thalamic rhythm is well marked. As in the preceding case sine waves at 3-a-second precede the "initial spike," which can be seen in all traces. Notice the constant relationship of the spike to the wave in the thalamic records. In order to show that the spread up the needle is not simply electrical, in fig. 11 two specimens of record are shown at higher amplification in fig. 11/1, rhythms are seen in the electroencephalogram and in the cortical traces while the thalamic traces are relatively silent, while in fig. 11/2 a rhythm of 4-a-second in the cortical trace and electroencephalogram is not reflected in the thalamic traces which show a transient 3-a-second rhythm. Thalamo-cortical independence of rhythm is therefore possible in this case, as in others (Williams and Parsons-Smith, 1949).

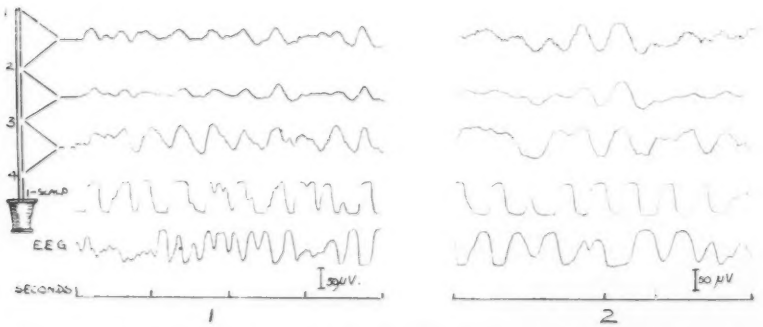


FIG. 11.—Records from Case 2 to demonstrate the independence of recording from thalamus, cortex and scalp, between attacks.

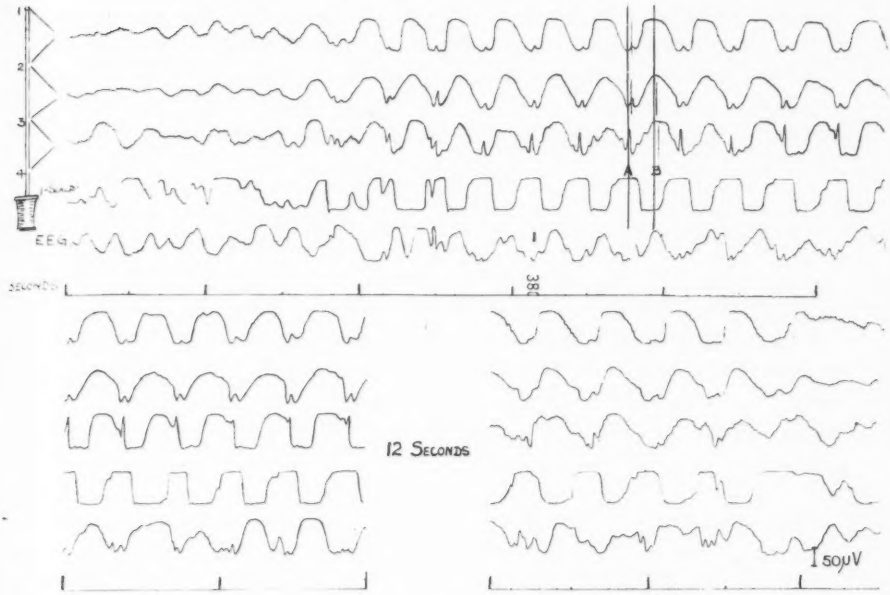


FIG. 12.—Case 2: At A and B vertical lines represent points in time. The spike is seen first in the electrodes near the cortex and last in those in the thalamus. The mid-point of the wave appears last in the cortical records (*see* text).

Fig. 12 shows another *petit mal* attack in this boy; it is recorded at faster speed but has all the appearances seen in fig. 8. At A and B synchronous lines are drawn to coincide with the mid-point of a spike and its succeeding wave. The mid-point of the slow wave was used for reference because of the inaccuracy of using its onset or its summit, but it is only completely reliable in the case of a sine wave. The short vertical lines in the other traces represent the mid-points of the same spikes and waves recorded from the other electrodes. It is obvious that the spike appears first at the cortical trace and is successively later in those from the deeper electrodes. The wave on the other hand appears first in the thalamic trace and last in the cortex. This has been so for a large number of spike-and-wave complexes which have been measured. An extension of the work to cathode-ray oscilloscopes is necessary to secure accurate measurements of the time intervals involved in this spread of activity. With the methods employed here the difference in the times at which the peak of the spike appears in the cortex and in the thalamus seems to be constant. This is also the case for the wave, and the time interval required for propagation of the wave and the spike between the same electrodes appears to be of the

same order. By finding the average time between the mid-points of a large number of spikes and succeeding waves in the thalamus and in the cortex, some idea of the spread of propagation can be gained.

AVERAGE TIME BETWEEN MID-POINTS OF SUCCEEDING SPIKES AND WAVES

In thalamus	0·203 sec.	
In cortex	0·231 sec.	
Difference	0·028 sec.	= 28 milliseconds.
Half difference	0·014 sec.	= 14 milliseconds.

The time taken for the complete cycle of events between thalamus and cortex is therefore about 28 milliseconds. This includes the initiation of the spike, apparently deep in the cortex, possibly its spread to the surface of the cortex, its spread down to the thalamus, and the subsequent initia-

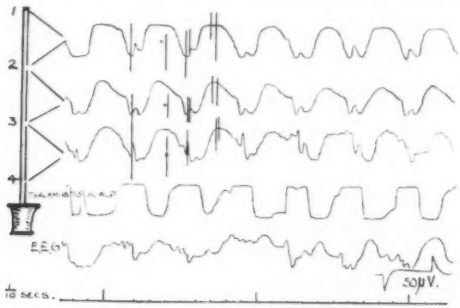


FIG. 13.—To demonstrate the lateness of the spike in the deep recordings compared with the superficial, and the reverse for the mid-point of the wave. Two consecutive wave-and-spike complexes are compared in three traces.

tion of the wave in the thalamus, and then its spread in turn to the deep part of the cortex. If the speed of propagation of the wave and the spike are in fact equal and they certainly appear to be similar, the total time taken for the spike to travel from cortex to thalamus will be of the order of 14 milliseconds. The time taken by the wave to return will be of the same order. So little is known about normal cortico-thalamic integration that discussions of these measurements is speculative.

The sequence of events which has been described earlier suggests that at the beginning of a *petit mal* attack a rhythmic 3-a-second wave beginning in the thalamus initiates a spike discharge deep in the cortex which recurs at about 3-a-second. This spike seems to travel from cortex to thalamus, taking about 14 milliseconds to do so. There it precedes the next wave by a constant interval. This wave then travels to the cortex at about the same rate as the spike has travelled and a further spike then appears deep in the cortex. This cycle is repeated until the interval

between each cycle begins to lengthen. When this has occurred beyond a certain limit the spike attenuates, fails to reach the thalamus and the process come to an end. The whole phenomenon of the *petit mal* discharge consequently depends for its initiation upon a thalamic rhythm and for its continuation upon a repetitive cortico-thalamic discharge.

Discussion

The observations in this paper refer entirely to true *petit mal,* in which frequent brief attacks of loss of consciousness, usually in children, are associated with 3-a-second wave-and-spike activity in the electroencephalogram. In an attempt to make a clear distinction between these attacks and others in which brief loss of consciousness occurs, they have been differentiated as "juvenile *petit mal*" since *petit mal* was originally a clinical term which cannot now be usurped by electroencephalographers without causing some confusion (Williams, 1950). In these cases of juvenile *petit mal* the wave-and-spike discharge is always generalized—Jasper and Fortuyn (1947) say: "We have never observed the complete picture of bilaterally synchronous 3 per second wave-and-spike discharge of the classical form from a focal epileptogenic lesion of the cortex." It is with these bilaterally synchronous discharges that we are here concerned.

Because these rhythms were bilaterally synchronous, and because they remained synchronous and generalized after section of the corpus callosum, Hursh (1945) suggested that they may have a subcortical origin, and, without using intracerebral electrodes, he suggested the thalamus as their site of origin. In this he supported the idea put forward by Jasper and Kershman (1941) that there must be a subcortical "pace maker" for the *petit mal* discharge, since the timing of the rhythms in homologous areas of the brain was absolutely synchronous. Penfield and Jasper (1947) supported the view on theoretical grounds when they postulated a diencephalic origin for *petit mal,* where there are mechanisms in which "afferent systems of both sides find their ultimate target, the efferent systems their origin."

We have referred in the introduction to the indirect evidence from animal experiment that subcortical structures are involved in the discharge of *petit mal,* but the evidence in man has been theoretical, based mainly upon the generalized symmetry and synchrony of the wave-and-spike discharge over the cortex. Jasper and Kershman (1941), for instance, give examples of the exact mirror image of these discharges in the two hemispheres. Although this generalized discharge is usual, the wave-and-spike complex is often more evident in the frontal lobes than elsewhere (Gibbs, Lennox and Gibbs, 1936.) The evidence from animal experiments, already quoted, that the *petit mal* wave-and-spike complex may have its origin in

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the thalamus, has been derived from the converse method of stimulating the thalamus in different ways and recording the associated electrical rhythms, including the wave-and-spike, from the cortex. More direct evidence in man that the thalamus is involved in the *petit mal* discharge was recently offered by Spiegel and Wycis (1950) who found, by recording directly from the thalamus, that the seizure discharges appeared first in the thalamus. The discharges were seen next in the frontal cortex, and they were still present in the thalamus after the cortical discharges had subsided. The present results show not only that the thalamus is involved in the *petit mal* disturbance, but they go some way to showing in what way it is implicated. Very much more, and more detailed work, will be needed to extend these initial and limited observations. They are limited in two important ways.

(1) Recognition of the placement of the electrodes within the thalamus is undertaken *after* the experiment. Introduction of the electrodes with an accuracy similar to that possible in cats is quite essential. Although topographical measurements of the electrode positions in relation to the ventricles, based on Talairach, Ajuriaguerra, and Hecaen's diagrams has been used in these cases, it is best not to refer to the electrode placements within the thalamus in terms of nuclei at present.

(2) Time relationships and wave forms must be studied at much greater speeds with multiple sweep cathode-ray oscilloscopes.

The Thalamic Origin of *Petit Mal*

That the wave-and-spike discharge actually originates in the thalamus is shown in the preceding results in the following ways.

(*a*) The 3-a-second rhythm starts there and is seen to increment in the thalamus for nearly a second before appearing in the cortex. Spiegel and Wycis (1950) have observed the same thing.

(*b*) Phase reversals show with certainty that the 3-a-second wave arises deep in the thalamus both before it has appeared in the cortex, and after it has done so.

(*c*) The 3-a-second wave invariably precedes the "initial spike" and indeed may be responsible for the initiation of this spike.

(*d*) The mid-point of the wave is earlier in the thalamus than the cortex.

The Beginning of the Attack

The *rhythm of 3-a-second* is seen to begin deep in the thalamus. This is of great interest because of the diffuse and symmetrical appearance of the wave-and-spike complex over the scalp. Morison and Dempsey

(1942 and 1943) found that repetitive stimulation of the medial part only of the cat's thalamus induced rhythmic changes throughout both hemispheres. Each component of these changes was induced by a preceding stimulus but repeated stimuli were needed for the initiation of the rhythm. This they called the "recruiting response" of the cortex to intralaminar simulation. The rhythms were symmetrical and synchronous in the hemispheres, and were particularly evident in the frontal lobes. In these human subjects with *petit mal* on the other hand the rhythms in the thalamus were apparently spontaneous. They increased in size and reached the cortex. When the rhythm had become established a spike occurred in the traces.

This *initial spike* did not arise in the thalamus, as the preceding wave had done. By phase reversal it was seen to originate deep in the cortex. It must again be emphasized that it is impossible to be certain in any one human case exactly where the electrode is in relation to the plane of the cortex. All the records have shown, however, that the spike arises more than 1 cm. deep to the inner table between electrodes 3 and 4 in figs. 2 and 3 and it is clearly not arising in the upper layers of the cortex at the convexity. There is no reason to suppose its origin is sub-cortical. Turning to animal experiments for guidance in this, Dusser de Barenne and McCullough's work on the origin of strychnine spikes showed that the spike arose in the deep layers of the cortex, travelled to the surface of the cortex and then returned. The present results are compatible with such a site of origin of the spike in man. The records show that the "initial spike" appears in all traces, although its voltage is not necessarily high. In this it may differ from its successors. While phase reversal seems to show that the spike arises deep in the cortex, time-relationships show that it travels down to the thalamus, the time taken being not less than 14 milliseconds. To be more exact the average difference between the mid-points of spike-and-wave in cortex and thalamus is 28 milliseconds, and as measurements show that the time the wave takes to reach the cortex is about the same as that taken by the spike to reach the thalamus, the estimate for both is 14 milliseconds. Jasper and Fortuyn found a delay of 10 to 15 milliseconds between stimulation of the dorsomedian nucleus in the cat, and the appearance of the initial component of the response in the frontal cortex. If the spike in fact travels to the surface of the cortex and back as Dusser de Barenne and McCullough's work suggests, before it is propagated to the thalamus, this interval could be explained by synaptic delays. As the electrodes are arranged in a row from scalp to thalamus, we have only studied spread in this plane but confirmation of the temporal spread by phase-reversal along the line of electrodes makes it unlikely that the spike is travelling in any other plane.

We have for simplicity so far deliberately used cases with "pure" wave-and-spike complexes, and have not studied the behaviour of multiple spikes. The records show, however (*see* figs. 7 and 8), that when more that one spike occurs the spikes travel to the thalamus but there is only one that has a constant relationship to the wave. Measurements show that the spike-wave relationship is surprisingly constant in the thalamus. As the waves appear first they may be the initiators of the "initial spike," and after that the wave-and-spike may be mutually interdependent for their repetition, and it seems as if the spike is responsible for the next of the succeeding wave, the continuity of the attack being dependent on the succeeding spikes. In the work which has been done on animals in which repeated stimulation of the thalamus has evoked a rhythmic cortical response in the cortex, the similarity to the wave-and-spike discharge is sometimes striking. But in Lewy and Gammon's experiments (1940) the wave-and-spike discharge continued after stimulation had ceased, and in Jasper and Fortuyn's paper (1947) in some instances *a wave-and-spike complex* followed each stimulation. Although the *petit mal* discharge can be mimicked by repetitive stimulation of the intralaminar structure of the cat's thalamus, it is well to remember that it is only mimicry, which may be quite far removed from the actuality of a wave-and-spike complex which is self-perpetuating and which uses (so this work indicates) a thalamo-cortical, cortico-thalamic circuit in doing so. Walter (1946) pointed out that the wave-and-spike complex is a unit in which two waves of greatly different frequency are intimately linked.

The wave undergoes a curious change after the "initial spike" has occurred. It maintains its wave-form and frequency but its site of origin ascends above the next electrode. This electrode is more lateral and posterior in the thalamus. It is in fact just below the ventricular surface of the thalamus above the pulvinar, in the postero-lateral part of the thalamus. No explanation can yet be offered for this change of origin of the wave. Although one cannot be dogmatic about intrathalamic topography in these cases, one cannot say that the 3-a-second wave, even at its initiation, arises in the median, intralaminar portion of the thalamus as might be predicted from the animal experiments which have been quoted. The wave seemed to originate from the substance of the postero-lateral part of the thalamus, and then, after the "initial spike" near the ventricular surface of the thalamus. As a phase reversal simply reflects a plane, and not necessarily a point of origin, it would be best simply to conclude from this work that the 3-a-second wave arises deep in the substance of the thalamus, and after the "initial spike" originates more laterally near the surface of the thalamus. There is no evidence to relate these results on this point to the important results of thalamic stimulation in the cat.

The Developed Attack

The features of the wave-and-spike discharge of the developed *petit mal* attack which are seen in the electroencephalogram are well known, and few need be mentioned here.

(1) Jasper and Fortuyn (1947) emphasize that in the electroencephalogram the wave is the more constant disturbance, for the spike may disappear in an attack, its position on the wave varies in different parts of the cortex, and its phase may change in relation to the wave.

(2) The initial 3-a-second waves may augment before the wave-and-spike complexes begin at 3-a-second, and the rhythm slows to about 2·5-a-second before the attack ceases.

In contrast to this lack of constant relationship between wave-and-spike in the cortex, after the augmentation of the 3-a-second wave first in the thalamus and then in the cortex, and after the "initial spike" has occurred, there is a very close relationship between wave-and-spike in the thalamus. The spike-spike interval varies very little apart from lengthening towards the end of the attack, and the spike-wave interval is constant in the thalamus, suggesting that it is here, and not in the cortex, that the wave-spike linkage occurs. In some attacks the constancy of the spike-wave interval in the thalamus is so different from its inconstancy in the cortex that an explanation may be a variation in the speed of propagation of the wave up to the cortex. This needs further study. Apart from vicarious spikes modifying the wave form, there seems no marked variation in the spike-wave complex in the thalamus of the kind which is commonplace in the cortex. The complexes in different parts of the cortex have not been compared with those in the thalamus.

Cessation of the Attack

One of the many mysteries of epilepsy is why an attack ceases. In all the wave-and-spike discharges studied the spike arising deep in the cortex becomes of progressively lower voltage in the 3 or 4 final spikes. The wave does not begin to decrease in size or persistence until this has happened. The waves are therefore present before the spikes start and after they end —they alone are present at the beginning and the ending of the attack. The spike with its regular occurrence seems to be essential to the continuity of the rhythms and maybe the "pace-maker," and it seems likely that the complex as a unit has a natural frequency of about 3-a-second, which depends on the time to complete both phasic potential changes within a set neuronal system. If this is so the ending of the attack is brought about by the lengthening of the spike-spike interval beyond the narrow limits within which the wave complex can continue to reproduce itself. It

seems certain that the part of the thalamus from which the wave arises is of importance in this respect, for if an attack ends and the wave recurs in its "final" instead of in its initial position, though it recurs at 3-a-second instead of at its slower rate no spikes occur, and the attack is stillborn. The fact that the wave can recur immediately at 3-a-second (fig. 6) supports the idea that it is the increase in the spike-spike interval that heralds the end of the attack.

The Nature of *Petit Mal*

The essential part played by the thalamus in the disturbance of *petit mal* will probably prove unique in the epilepsies. There are two ways in which interference with the thalamus and cortex may alter behaviour:

(1) By modifying the basic electrical state of the cortex, in the way suggested by Bishop (1949).

(2) By preventing the integration of the afferent mechanism upon which the whole basis of awareness, memory, and behaviour rests.

Bishop suggests that the apparently spontaneous rhythmic electrical activity of the brain has a function in modifying the induced activity of neurones in it. What happens in response to stimulation is affected by the characteristics of the spontaneous electrical activity at that time, or by what constitutes its substrate. It is obvious that profound modification of neuronal activity throughout the brain may take place during the dramatic rhythmic discharge of *petit mal*.

Jasper (1949) has suggested a thalamic "reticular" system, having its origin in the intralaminar structures, and having diffuse representation throughout the hemispheres, stimulation of which will induce rhythmic electrical responses throughout the hemispheres, of the kind first described by Morison and Dempsey.

Moruzzi and Magoun (1949) have shown the presence of an ascending system in the brain-stem, a reticular activating system, stimulation of which greatly alters the spontaneous electrical activity of the whole cortex. It "activates" the electroencephalogram since it abolishes slow rhythmic activity. It is mediated to some degree through the diffuse projection system of the thalamus called by Jasper the thalamic reticular system. Lindsley, Bowden and Magoun (1949) have found that section of this ascending system in the mid-brain had the reverse effect, for high-voltage slow waves appeared in spindles throughout the electroencephalogram, as they do in sleep or anæsthesia.

Interruption of afferent mechanisms of the brain-stem and thalamus therefore greatly affects the electrical activity of the whole cortex, but we also know from the work of Hess (1949) and of Hunter and Jasper

(1949) that stimulation of the intralaminar structures of the thalamus will cause inactivity (akinesia) and arrest of the experimental animal's movements. This motor inactivity must surely be secondary to a breakdown in the integration of proprioception and exteroception without which movement is impossible. This has already been discussed in relation to thalamic discharges which are seen in the thalamus of patients in akinetic stupor (Williams and Parsons-Smith, 1951). The present results suggest that the same mechanisms are implicated in a fundamental way in *petit mal,* so that the immobility, akinesis, loss of "awareness" and the amnesia of *petit mal* may be secondary to an interruption of integration on the afferent side of the organism. Initiation or continuity of any executive process in the cerebral cortex has become impossible through physiological isolation at the level of the thalamus. This is in contrast to other forms of epilepsy, in which the disturbances—so far as is known—are limited to cortical systems concerned with effector mechanisms. In these, therefore, the disturbance is higher up the rapidly expanding system which leads to feeling, movement (behaviour) and thought. The disturbance may be considered to be on the efferent side of the organism, if the analogy of the simple reflex arc is used, knowing that when it is applied to the cerebral hemispheres it is an over-simplification. Disorders of feeling, behaviour, and thought have therefore occurred in those forms of epilepsy because of stimulation of effector neurones, whereas in *petit mal* the same neurones are made inert through their isolation from the afferent stream upon which their function depends.

Summary

Electrographic records have been obtained from the thalamus, white matter, and cerebral cortex during *petit mal* in children. A large number of attacks have been studied in 6 cases.

The sequence of events in the *petit mal* attack was found to be:

(1) A rhythm of 3-a-second begins in the thalamus. This rapidly increases in voltage and persistence until it reaches the cortex.

(2) When it has done so a fast spike originates deep in the cortex. The "initial spike" usually has a high voltage and it travels down to the thalamus.

(3) When this spike reaches the thalamus the site of origin of the 3-a-second wave alters and becomes more superficial (lateral and ventral) within the thalamus.

(4) The wave which has now arisen in a new position in the thalamus is then followed by a spike which seems to arise deep in the cortex. This process is repeated in a stereotyped way.

(5) As the attack proceeds the speed of the rhythm usually falls slightly from 3 to about 2·5-a-second. After it has done so the voltage of the cortical spike rapidly drops. The spike then ceases and the wave then similarly decreases in size and disappears.

(6) Although the thalamic rhythm seems to be responsible for the cortical spike, the spike seems to be essential for the continuation of the 3-a-second rhythm; for if the rhythmic wave recommences and no spike occurs, the rhythm is not sustained.

(7) The average time taken for the spike to travel from the deep part of the cortex and ultimately to reach the thalamus is about 14 milliseconds, and that for the wave to return is of the same order.

(8) Each step in this chain of events is essential for the complete phenomenon of the "spike and wave discharge" of *petit mal* epilepsy. It seems, for example, to be necessary for the development of an attack for the initial 3-a-second wave to arise in a constant position deep within the thalamus. If this rhythm recurs in the secondary more superficial position which it adopts in a developed attack, it does not initiate a cortical spike. The rhythm then dies and the attack is stillborn.

(9) These results have been related to the results of animal experiments carried out in other laboratories and to observations on patients in stupor.

(10) The hypothesis is advanced that the clinical state of *petit mal* epilepsy is due to a disturbance in the thalamus which causes a rhythmic discharge throughout the cortex. The effect of this is a failure in the integration on the afferent side of the organism. This results in secondary akinesis, flaccidity, and amnesia, which form the basis of the disability in the *petit mal* attack. Many of the differences in observed behaviour in *petit mal* and *grand mal* attacks can be explained upon this basis, regarding *petit mal* as a periodic disorganization of the afferent, affector side of the organism, which inhibits all awareness and "spontaneous" behaviour, in contrast to the other forms of epilepsy in which the disorganization occurs in the effector mechanisms.

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THE PATHOLOGY OF SPINAL CORD LESIONS AND THEIR RELATION TO THE CLINICAL FEATURES IN PROTRUSION OF CERVICAL INTERVERTEBRAL DISCS

(A Report of Four Cases)

BY

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Many have written on the subject of protrusion of intervertebral discs in the cervical spine. Most of the work has been concerned with the clinical aspect of the problem and with the structural changes in the disc and the surrounding osseous and fibrous structures. Notable among the workers in this field are Stookey (1928, 1940), Elsberg (1925, 1931), Bradford and Spurling (1945), Mixter and Barr (1934), Mixter and Ayer (1935), Eaton (1941, 1946), Keegan (1947), Hawk (1936), Elliot and Kremer (1945), Spillane and Lloyd (1951), Frykholm (1951) and Allen (1952), whose main emphasis is clinical. Schmorl (1931), Andrae (1929) and Beadle (1931) were interested in the morbid anatomy of the disc. Reports dealing with changes in the spinal cord in disc herniation are relatively infrequent. The ones we are acquainted with are those of Middleton and Teacher (1911), Browder and Watson (1945) and Brain *et al.* (1952).

The pathological changes in the cord and their relation to the clinical features in 4 cases with prolapse cervical intervertebral discs are presented.

The tissues were embedded in celloidin. The various segments of the cord were examined by the following staining methods:

Weigert Pal, hæmatoxylin van Gieson, phosphotungstic acid hæmatoxylin, Loyez and Nissl, and, in some instances, by the silver impregnation method of Gros-Bielschowsky.

The levels of the cord have been checked against those of Bruce (1901).

Case 1.—Summary of Clinical Course

J. Z. (Hosp. No. 26198), a man aged 51, was admitted to the National Hospital, Queen Square, under the care of Dr. Brinton, in October 1950. with weakness of the left lower limb for twelve months, of the left hand for nine months, urinary hesitancy for six months and stiffness and pain of the neck for seven months.

Examination revealed a left spastic hemiparesis with bilaterally hyperactive deep tendon reflexes and extensor plantar responses, as well as a slight impairment of temperature and pain appreciation on the right below an indefinite mid-thoracic level. Myelography showed a break in the contrast medium at the level of the interspace between the third and fourth cervical vertebræ.

Death resulted from air embolism during a decompressive laminectomy.

Details of Clinical Features

No relevant information was elicited from the family history. Six years prior to admission the right eye was burned by a cinder. Gradual deterioration of vision followed and one year later he had no useful sight in that eye.

In October 1949 he found that his left foot was scraping the ground. The left leg then became weaker. The left knee gave way while walking on two occasions in September 1950. Weakness of the left hand came on in February 1950 and spread to involve the left wrist. In March 1950 he began to have recurrent neck stiffness with pain on movement. Turning his head to the left produced a twinge of pain in the left loin. Intermittent difficulty in initiating and continuing micturition had been present since April 1950.

On examination his sense of smell was moderately impaired bilaterally. His pupils were small, did not react to light and contracted only slightly on convergence.

He had a left spastic hemiparesis with the weakness more marked proximally in the upper limb and distally in the lower limb. The deep tendon reflexes were bilaterally hyperactive. The left abdominal reflexes were decreased and there was left ankle clonus. Both plantar responses were extensor. Temperature and pain appreciation was impaired on the right below an indefinite mid-thoracic level. Vibration sense was decreased on the right below the level of the clavicle. Joint position sense was not impaired. The blood pressure was 115/65.

X-ray examination showed fusion of the bodies and laminæ of the second and third cervical vertebræ and backward displacement of the fused vertebræ upon the fourth vertical vertebra. Myelography revealed a break in the column of contrast medium at the C.3–4 level (fig. 2). The cerebrospinal fluid pressure was 140 mm. on lumbar puncture and rose and fell freely on jugular compression. The fluid was clear and colourless with 2 cells per c.mm. The total protein content was 50 mg. per cent. Wassermann's reaction of the blood and cerebrospinal fluid was negative.

A subperiosteal laminectomy of the second, third and fourth cervical vertebræ was performed on November 9, 1950. Just after a wide bony decompression had been made, the patient's breathing and pulse stopped. Immediately after this, crepitus was felt in the line of both internal jugular veins but not elsewhere.

The post mortem examination was conducted by Dr. W. Blackwood two and a half hours after death. The bases of the lungs were congested and frothy blood filled the right ventricle and the arteries of the lungs. The disc between the third and fourth cervical vertebræ bulged slightly backwards on forward flexion and markedly on backward extension of the spine. It had a greater antero-posterior diameter and a lesser thickness than normal. The second and third cervical vertebræ were fused and displaced backwards upon the fourth cervical vertebra. The overlying spinal cord, at the level of the fourth to fifth cervical segments, was compressed in its antero-posterior diameter and was greyish in colour. This compression and greyness affected both the central and lateral parts of the cord, being more marked on the left.

The intervertebral foramina of the cervical spine, removed at autopsy, were normal.

Summary of Histological Changes

The fifth cervical segment was the most severely damaged. It was markedly flattened antero-posteriorly (fig. 1). Swelling of myelin and axons, demyelination and loss of axis cylinders were noted in both postero-lateral columns and in the left anterolateral column. There was loss of axons in both posterior root entry zones and at the periphery of the cuneate fasciculus.

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Cephalad to this level, ascending degeneration was present in the left lateral column in the distribution of the spinocerebellar and spinothalamic tracts. It was also present in the posterior columns as a result of the damage to the posterior root entry zones and the lateral parts of the cuneate fasciculi of the fifth cervical segment. The zone of damaged fibres was displaced medially as one moved cephalad by additions of normal fibres to the lateral part of the dorsal columns. In the posterolateral columns demyelination and axon loss commenced at the fourth cervical segment and were present in the long descending tracts below this level.

The anterior horns showed marked neuronal loss on either side at the fifth cervical segment. Many of the remaining cells showed peripheral chromatolysis and a few, central chromatolysis and vacuolation of cytoplasm. Proliferation of astrocytes, gliosis and foci of microglia occurred in the zones of demyelination and of nerve cell loss (fig. 4).

The small blood vessels in the damaged grey and white matter were prominent and had thick collagenous adventitial coats. This change was most marked at the region of maximal cord damage (fig. 5). The leptomeninges were slightly thickened over the cervical cord.

Detail of Histological Changes

The Most Damaged Region

C.5. This segment was markedly flattened antero-posteriorly (fig. 1). The severity of the lesion varied at different levels of the segment. Swelling of myelin and axons, demyelination and loss of axis cylinders were noted in both posterolateral columns, in the left anterolateral column about the course of the anterior root fibres and in the cuneate fasciculi adjacent to the posterior horns. Loss of axons was noted in both posterior nerve root entry zones. The anterior and posterior horns showed marked neuronal loss which was almost complete at some levels. Many of the persisting nerve cells showed peripheral chromatolysis. A few exhibited central chromatolysis and vacuolation of the cytoplasm. Glial stars were present and proliferation of astrocytes was marked (fig. 4). Regions of necrosis and small cavities were found on both sides, mainly in the grey matter, but also in the white matter of the most severely damaged part of the segment (fig. 3).

The small blood vessels in the grey and in the white matter were prominent and each had a thick collagenous adventitial coat (fig. 5). Many vessels showed perivascular cuffing by small round cells and phagocytes filled with granular material.

Cephalad to the Most Damaged Region

C.4. The intima of the anterior spinal artery showed a mild degree of thickening. The adventitia was moderately thickened. Demyelination was present in each cuneate fasciculus extending from the periphery of the cord to the lateral part of the white commissure. A zone of well-myelinated fibres separated this demyelinated region from the posterior horn. Demyelination and axon loss, more marked on the left, had occurred in the lateral columns, mainly in the more central part of the posterolateral columns and, to a lesser extent, in the anterolateral regions. Swelling of myelin and axons was present around the demyelinated regions.

The nerve cells of the anterior horns were well preserved. In the right posterior horn small cavities were present. Occasional granular corpuscles and small round

cells were found in the tissue lining the cavities. The demyelinated area and the injured posterior horns were gliosed. The vessels appeared more prominent than normal in the damaged regions of the cord. Their walls were thickened.

C.3 (fig. 1). Mild round-cell perivascular cuffing was seen in some of the leptomeningeal vessels. The intima of the anterior spinal artery was slightly thickened. The dorsal and ventral roots were healthy. The cuneate fasciculi of the dorsal columns showed ascending degeneration in a distribution which indicated that it was secondary to the lesion of the posterior roots and cuneate fasciculi of the fifth cervical segment. Swelling of myelin and axons and demyelination had occurred in the periphery of both lateral columns in the distribution of the spinocerebellar and spinothalamic tracts. Astrocytic proliferation had taken place in the damaged regions of the white matter.

No structural change was found in the anterior horns.

Caudal to the Most Damaged Segment

C.6, C.8 and D.1. The posterior nerve roots appeared healthy. Marked demyelination and axon loss were present in the posterolateral columns of both sides, but more severe on the left. The myelin sheaths and axis cylinders around these demyelinated regions were swollen. Some of the anterior horn cells on either side were undergoing chromatolysis. There was some collagenous thickening of the vessels in the damaged white and grey matter.

D.7 (fig. 1), *and L.5.* The posterolateral columns exhibited demyelination and axon loss which were more marked on the left side. Gliosis had occurred in the damaged zones. The nerve cells were well preserved. Slight collagenous thickening of the adventitia was seen in the demyelinated white columns.

Clinico-Pathological Correlation

The weakness and the extensor plantar responses are attributable to the lesions of the crossed pyramidal tracts. The urinary hesitancy is related to the damage of the posterolateral columns. (McMichael, 1945). The proximal distribution of the weakness in the left upper limb is due to the lesion in the grey matter of the fifth cervical segment. The impairment of pain and temperature sensation on the right is related to the degeneration in the left lateral column in the position of the lateral spinothalamic tract. The decrease in appreciation of vibration on the right below the level of the clavicle cannot be readily explained. The accepted view is that the vibration pathway lies solely in the ipsilateral posterior column. In this case there was no evidence of any abnormality in the portion of the posterior columns subserving the trunk and lower limbs. This raises the question whether injury to pathways other than the dorsal columns may cause impairment of appreciation of vibration.

Case 2.—Summary of Clinical Course

R. R. (Hosp. No. 22600), a woman aged 72, was admitted to the National Hospital, Queen Square, under the care of Dr. Meadows on March 17, 1950. She had suffered from cramps in the thighs and weakness of legs from October 1949, and from flexor spasm of the lower limbs since February 1950. Numbness of the hands came on in November 1949. She had wasted small hand muscles and a spastic quadriplegia. Temperature and pain sensation were decreased below C.7. She died on March 30, 1950, from pulmonary embolism.

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Detail of Clinical Features

Relevant information was not elicited from the family history. She had phlebitis affecting the left leg in 1942. About 1940 she had wasting of the right hand, but this had remained stationary since. In October 1949 she began to have cramping pain in the back of both thighs at rest and on exercise. At the same time her left leg began to tire and drag when walking. The right leg became weak in January 1950. The weakness of both lower limbs increased so that from February 1950 she feared to walk without support lest her legs should give way under her. Flexor spasms were present from February 1950.

In November 1949 her right forefinger and thumb became numb and the numbness spread to affect the whole hand. She believed her right hand had become weak as well as numb from November 1949. About Christmas 1949 the left thumb became partly numb with spreading of the numbness to involve all the fingers. From January 1950 she had a sensation of a tight band around her waist. From February 1950 a mild ache was present in the posterolateral aspects of the neck and spread to the shoulder tips. The ache was aggravated by turning of the head and by coughing. There was no sphincter disturbance.

On examination her intellect was somewhat deteriorated. There was marked wasting of the radial aspect of the right thenar eminence and of the first dorsal interosseous space, with slight dorsal guttering on the same side. Similar but slight changes were present in the left hand. All the intrinsic muscles of the right hand were markedly weak. There was moderate weakness of wrist and elbow extension and slight weakness of elbow flexion bilaterally, but more so on the right.

She was unable to sit up without using her arms. The flexors of the hips were markedly weak and those of the knees moderately so, and extension of the knees and dorsiflexion of the feet were less powerful than normal. The weakness was bilateral but more marked on the right. Tone was increased in the elbow extensors and in the lower limbs. The deep tendon reflexes were active and equal. The abdominal reflexes were absent, both plantar responses were extensor and there was bilateral ankle clonus.

Appreciation of light touch was decreased over the dermatomes C.7 to D.2 bilaterally. Appreciation of pain and temperature was impaired from C.7 downwards, most marked over the dermatomes C.7 to D.4. Two-point discrimination was decreased over her fingers. Postural sense was grossly impaired in the medial three fingers on the right and moderately so over the medial three fingers on the left. It was normal in the toes. Vibration sense was absent in the upper limbs below the elbows.

The blood pressure was 180/100. Her vessels were thought to be arteriosclerotic. X-rays revealed osteophytic spurring in the cervical and dorsal spine. A myelogram showed interruption of the column of contrast medium at the level of the interspaces between the sixth and seventh cervical and the seventh cervical and first thoracic vertebræ. No contrast medium would pass cephalad to the level of the fifth cervical disc. Cerebrospinal fluid pressure at lumbar puncture was 135 mm. and there was a free rise and fall on jugular compression. The fluid was clear and colourless and no cells were found. The protein content was 110 mg. per cent with a positive Pandy. Wassermann's reaction of both blood and cerebrospinal fluid was negative.

On March 30, 1950, she suddenly collapsed, complaining of tightness across her chest and difficulty in breathing. She died within forty-five minutes.

A post mortem examination was carried out by one of us (W. G. P. M.) three and a half hours after death. The heart showed fatty degeneration of the papillary muscles and some fibrous replacement of the myocardium of the left ventricle. The pulmonary artery at its origin contained a large coiled-up mass of ante-mortem thrombus, a portion of which extended into one of the larger vessels of the left

lower lobe. The left saphenous vein was filled with adherent thrombus from below the knee to its junction with the femoral vein.

The cerebral vessels did not show any gross evidence of degenerative change.

The intervertebral discs of the spinal column were prominent and projected into the spinal canal in the cervical and lumbar regions. The cervical discs became more prominent on hyperextension of the neck. The discs indented the anterior surface of the spinal cord at the intersegmental levels from the fourth cervical to the first thoracic segment. The disc between the fourth and fifth cervical vertebræ was most prominent and indented the cord most deeply between the fifth and sixth cervical segments. A sagittal section of the cervical spine demonstrated bony union of the bodies of the third and fourth cervical vertebræ.

The intervertebral foramina were narrowed by osteophytic spurs on both sides, but more on the left.

The thenar muscles of the right hand were very wasted.

Summary of Histological Changes

The sixth cervical segment was flattened antero-posteriorly and showed maximal loss of myelin (fig. 1). Here there was swelling of myelin sheaths and axons in the ventral parts of both posterior columns and in both lateral columns, more marked on the right. Ascending degeneration of similar distribution in the posterior columns and the peripheral parts of the lateral columns could be followed cephalad as far as the first cervical segment. Demyelination was also present in the deeper portion of the anterolateral columns on both sides from the fourth cervical segment cephalad in the distribution of the lateral spinothalmic tract. This lay posterior to the normally pale triangle of Helwig in the upper segments.

Pallor of myelin was apparent in the right posterolateral column of the fifth cervical segment. The sixth cervical segment showed pallor of both posterolateral columns, more marked on the right, and this could be traced caudally in the descending tracts.

Loss of nerve cells was noted in the anterior horns of the cord from the fourth cervical to the first thoracic segment inclusive (fig. 6). The loss was more severe on the right. Some of the remaining cells were undergoing chromatolysis and neuronophagia. Chromatolysis and increased satellitosis were seen in the posterior horns. Gliosis occurred in the injured regions of the cord. The posterior nerve roots were undamaged.

The blood vessels were prominent in both grey and white matter. Their lumina were wider than usual and their adventitious coat greatly thickened and fibrous. Some vessels in both grey and white matter showed perivascular cuffing by small round cells. The leptomeninges were slightly thickened and presented occasional foci of infiltration by small round cells.

The muscles of the right thenar and hypothenar eminences showed the changes typical of denervated muscle (fig. 7).

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Detail of Histological Changes

The Region of Maximal Myelin Damage

C.6. The sixth cervical segment was the most markedly flattened. It was elongated from side to side (fig. 1). Myelin preparations showed thinning and pallor of the anterior nerve roots, swelling of myelin and demyelination both centrally and peripherally in the lateral columns and in the ventral half of the dorsal columns. Prolifieration of astrocytes and fibre formation had occurred in the demyelinated regions of the cord. Both posterior nerve roots were thick and well myelinated and were not fibrosed. The contour of the anterior horns was altered by compression of the cord. Nerve-cell loss and proliferation of astrocytes were noted in both anterior horns. The changes throughout the segment were more marked on the right side. The vessels of both grey and white matter had thickened adventitial coats and were in some instances surrounded by small round cells.

Cephalad to the Greatest Myelin Damage

C.5. Both anterior nerve roots were thinned. The posterior nerve roots were well myelinated.

Demyelination of less severity than in the sixth cervical segment but similar in distribution was seen in the lateral columns. A triangular-shaped zone of demyelination with the base towards the commissure occupied the anterior part of each dorsal column. A small elliptical zone of demyelination lay in the centre of the dorsal columns between these two pale regions. This demyelination did not correspond to the distribution of a lesion of posterior nerve roots. The demyelinated zones were sclerosed and around them the myelin sheaths and axons were swollen.

Loss of nerve cells and gliosis had occurred in both anterior horns, though to a greater degree on the right side. Gliosis was also present in the posterior horns.

The blood vessels throughout the demyelinated regions had thickened collagenous outer walls. This change was present, though of lesser severity, in the grey matter.

C.4. The fourth cervical segment presented pallor of the myelin in the peripheral part of the lateral columns, more marked on the right side. Demyelination had occurred in the cuneate fasciculi and in a central illiptical region of the gracile fasciculi. Around the demyelinated zones the myelin sheaths and axons were swollen.

The right anterior horn showed some loss of nerve cells and an increase of fibrous astrocytes. The vessels had thick collagenous walls and some of them were surrounded by small round cells.

C.3–*C*1. The first three cervical segments showed swelling of myelin and axons as well as demyelination in the dorsal columns and in the anterolateral columns deep to the triangle of Helwig (fig. 1). The anterior and posterior nerve roots did not present any lesion. At the third cervical segment and above, the anterior horn cells were well preserved. The blood vessels in all these segments had thick collagenous walls.

Caudal to the Greatest Myelin Damage

C.7. The posterior nerve roots were heavily myelinated. The segment showed swelling of myelin and axons and demyelination and gliosis of the posterolateral columns, more extensive on the right side. In the dorsal columns pallor of myelin was present only in the ventral part of the left cuneate fasciculus. Chromatolysis of the nerve cells and increase of astrocytes were seen in the anterior horns. Some loss of nerve cells had occurred. The vessels in the cord were surrounded by a thick wall of collagen.

C.8. The posterolateral columns were demyelinated and gliosed and more so on the right side. Around these regions the myelin sheaths and axis cylinders were

swollen. The anterior horns on both sides showed loss of nerve cells and proliferation of astrocytes, the changes being more marked on the right side. The right anterior nerve root was excessively thin. Both posterior nerve roots were well myelinated and did not show evidence of fibrosis. The vessels in the damage regions showed slight fibrous thickening of the adventitia.

T.1. The first thoracic segment showed myelin and axon swelling, demyelination and gliosis in the posterolateral columns. The anterior horns showed loss of nerve cells which was almosts complete on the right. Astrocytes replaced the nerve cells (fig. 6). The intermediolateral group of nerve cells was spared on each side. The posterior nerve roots were thick and well mylinated. The blood vessels were prominent with thick collagenous walls especially in the demyelinated zones. Myelinated fibres were present around the anterior spinal artery and vein.

T.12. The posterolateral columns were demyelinated and gliosed. The blood vessels of the parenchyma showed only slight thickening of their adventitia. The anterior horns did not show any obvious loss of nerve cells.

L.2. Degeneration was present in the posterolateral columns (fig. 1). No indication of nerve cell loss was noted. The anterior spinal artery showed intimal thickening. The vessels within the cord showed only a minimal degree of adventitial thickening.

Thenar Muscle (fig. 7)

A few distinct groups of normal and many groups of atrophied muscle fibres were present. The atrophied fibres were greatly diminished in calibre but were still of considerable length. Their cross-striations were preserved and the subsarcolemmal nuclei were greatly increased in number. In addition there were occasional hypertrophied muscle fibres in some of which the nuclei were large and pale and had migrated towards the centre of the fibres. The fibrous septa were thick and the blood vessels showed intimal thickening.

Clinico-pathological Correlation

The weakness of both lower limbs and the extensor plantar responses are explicable on the basis of bilateral pyramidal tract damage. The impairment of pain and temperature sensation is related to the lesions in the lateral spinothalamic tracts. The loss of light touch over the dermatomes C.7 to D.2 is due probably to a combination of lesions, one in the posterior columns and the other in the anterior spinothalamic tract regions. The posterior nerve roots in the cervical region showed no histological evidence of injury. Therefore the numbness of the hands cannot be attributed to damage to the posterior nerve roots unless one is willing to postulate a functional impairment without histological evidence of tissue changes. This numbness may be related to the lesions of the dorsal columns and the spinothalamic tracts. The wasting of the small hand muscles is related to the nerve-cell loss in the anterior horns of the first thoracic segment but may, in part, be caused by nipping of the motor roots in the intervertebral foramina.

Case 3.—Summary of Clinical Course

A. G., a man of 45, was admitted to the National Hospital, Queen Square, under the care of Dr. H. Howell in April 1936 with a four month history of pain in the

left shoulder and numbness of the left fingertips. The right foot had been dragging for two months. Weakness and numbness of the right hand had been present for one month. Complete urinary retention developed shortly before admission.

On examination he had a right spastic hemiparesis with absent abdominal reflexes and bilateral extensor plantar responses. Pain and temperature sensation was impaired bilaterally from the sixth to eleventh thoracic dermatomes inclusive and also in the right lower limb. Infection supervened upon the urinary retention, and he died four months after admission.

Detail of Clinical Features

No relevant information was obtained from the family history. About Christmas 1935 he developed a dull pain, which occurred mostly at night, in the left upper arm and behind the left shoulder. At this time he also had numbness and tingling in the fingertips of his left hand, most marked in the medial two fingers. In February 1936 the right leg was found to be weak and he dragged it along, wearing out the toe of his boot. At the same time there appeared numbness of the right lower limb, extending up to the hip. The right upper limb began to lose power in March 1936, starting in the thumb and index finger, and there appeared tingling and numbness in all the fingers of the right hand.

Beginning in March 1936 he had sharp pain, coming on only on coughing, extending across the back of his neck and down the outer side of the right arm into the thumb and index finger. He found that clenching his fist and abducting the arm prevented this pain. Occasionally on coughing, momentary pain like an electric shock passed down the right side of his body from the neck to the foot.

Since the beginning of April 1936 he had a band of numbness around his abdomen at the level of his umbilicus. One week prior to admission he suddenly developed complete urinary retention. His sexual power was good until the middle of March 1936, since when he had no libido.

On examination there was inconstant nystagmus to the left with occasional nystagmoid jerks to the right.

Grasp and the extensors and flexors of the right hand were weak. The flexors of the thighs were weak and the dorsiflexors of the right foot were feeble. Tone was increased in the right arm and leg. Intention tremor was present in the right hand and the heel-shin test was unsteadily performed on the right.

The deep tendon reflexes of the upper limb were active and equal. The abdominal and cremasteric reflexes were absent. The knee-jerks were equal and active. Neither ankle-jerk was obtained and both plantar responses were extensor. Anal sphincter tone was good.

Hypalgesia was present bilaterally over the eighth to twelfth thoracic dermatomes inclusive, with slight thermanæsthesia over the same region. The right lower limb was insensitive to pin-prick and temperature. Light touch, vibration, joint and position sense were everywhere normal.

Walking was barely possible and was grossly ataxic. The right leg was dragged along. His blood pressure was 125/80.

In April 1936 the cerebrospinal fluid was under a pressure of 160 mm. with a rapid rise and a slow fall on jugular compression. The fluid was clear and colourless and no cells were seen. It contained 130 mg. per cent of protein. The Pandy test was positive and the Lange curve was 0001210000. Wassermann's reaction of both blood and cerebrospinal fluid was negative.

A second lumbar puncture was carried out in July 1936. The initial pressure was 55 mm. and there was only a slow rise and fall on jugular compression. No cells were seen. The protein content was 50 mg. per cent.

Radiography revealed old spondylitic changes with scoliosis. The blood count was normal.

The patient's condition slowly deteriorated in hospital, although there were slight remissions. The ankle-jerks were occasionally obtained. Nystagmus developed into a more constant feature, first to the left and then on gaze to either side. Wasting and weakness of the dorsal interossei were noted in June, more marked on the right. By early July he had become bedridden with dribbling incontinence and urinary infection. The weakness increased but the sensory loss faded till only a vague blunting to pin-prick remained below the right knee. The anal and bulbocavernosus reflexes were lost.

The last examination was on August 11, 1936. The cranial nerves were found to be normal. The small muscles of both hands and the extensors of the hands and fingers were wasted, more on the right. The small muscles of the hands were very weak on the right, and moderately weak on the left. On the right, wrist and finger flexion were slightly weak and wrist and finger extension very poor. Wrist and finger extension on the left were slightly weak. There was very slight diminution of power in the right elbow flexors and extensors. Both quadriceps appeared wasted. Hip flexion, extension, abduction and adduction were very weak on the right and moderately so on the left. The patient was unable to flex the right knee and knee extension was also very weak. Dorsiflexion, plantar flexion, inversion and eversion of the foot was not possible on the right. He could flex but not extend his right toes. He had only very slight weakness at the left hip and knee.

Tone was increased in the flexors of the wrist and in the elbow extensors, more on the right side; while in the lower limbs the tone was increased to a greater degree on the left. The deep tendon reflexes were hyperactive with the exception of absent ankle-jerks. There was wrist clonus on the right and knee clonus bilaterally. A weak extensor plantar response was elicited on the left; no response was obtained on the right. No loss to pain or light touch was found. Appreciation of passive movement was slightly decreased in the fingers of both hands.

He died on August 14, 1936.

The post-mortem examination was carried out by Dr. J. G. Greenfield. Hæmorrhagic peritonitis was found in the lower abdomen. Early inflammatory changes were noted in the right kidney. A false passage connected a cavity in the infraperitoneal tissues with the bladder. The walls of this cavity were chronically inflamed.

No abnormality was present in the brain.

The spinal cord was pushed backward and compressed and thinned at the level of the intervertebral disc between the fourth and fifth cervical vertebræ. There was a rounded prominence of the prolapsed disc between the fourth and fifth cervical vertebræ and also of the discs between the vertebral bodies from the eleventh thoracic to the fourth lumbar vertebræ.

Summary of Histological Changes

The sixth cervical segment suffered the maximal damage (fig. 1) at which level demyelination had occurred in the anterior parts of both dorsal columns and most of the lateral columns. Ascending degeneration in the dorsal columns and the periphery of the lateral columns was present cephalad to this level. Descending degeneration of the posterolateral columns was present in all the segments caudal to the sixth cervical.

Loss of nerve cells occurred in the anterior horns from the fifth cervical to the first thoracic segments inclusive. Neuronophagia was seen at these levels. Gliosis occurred in the regions of nerve cell and myelin destruction.

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The small vessels in the regions of injury had thick collagenous walls (fig. 8). The posterior nerve roots were undamaged. The leptomeninges of the cervical cord were slightly thickened.

Detail of Histological Changes

Region of Maximal Damage

C.6. This segment was extensively damaged (fig. 1). The posterior nerve roots were well myelinated. Destruction of the bulk of the myelin, infiltration by fat phagocytes and repair by gliosis had taken place in the lateral columns. The astrocytes exhibited a marked degree of pleomorphism, multinucleated cells and gemästete astrocytes being present. The blood vessels showed perivascular round-cell infiltration.

Collections of fat phagocytes also occurred about the vessels of the lateral columns (fig. 8). The ventral third of the dorsal columns had undergone demyelination and gliosis. The greater part of one of the posterior grey horns had been severely damaged. There was loss of nerve cells, astrocyte proliferation and infiltration by fat phagocytes. The anterior horns showed severe nerve-cell loss, perivascular cuffing of the vessels and proliferation of astrocytes. Neuronophagia was also seen. The vessels of both the white and grey matter had a thick collagenous adventitial coat.

Cephalad to the Most Damaged Segment

C.5. The posterior nerve roots were well myelinated. Loss of myelin had taken place in the lateral columns extending to the periphery anteriorly. The anterior parts of the dorsal columns showed demyelination which did not lie in the distribution of posterior nerve roots. Loss of nerve cells had occurred in the anterior horns. Neuronophagia was seen in one of the posterior horns.

C.4 (fig. 1), *C.3, C.2 and C.1.* The dorsal columns presented demyelination and gliosis of the cuneate fasciculi and in the periphery of the lateral columns, where swelling of myelin sheaths and axons was also noted. The pyramidal tract regions were not demyelinated. The anterior horn cells were well preserved.

Caudal to the Most Damaged Segment

C.7. The posterior nerve roots were thick and heavily myelinated. Severe demyelination and axis cylinder loss had occurred in the lateral columns. The astrocytes replacing the axis cylinders and myelin showed considerable pleomorphism. A thin band of demyelination and gliosis was present in the anterior part of the cuneate fasciculi. The anterior horn cells were slightly reduced in number. The vessels had thick collagenous walls and some had collections of small round cells in their perivascular spaces.

C.8. The posterolateral columns were extensively demyelinated and gliosed. No change was found in the dorsal columns or the posterior nerve roots. The anterior horns showed some loss of nerve cells.

T.1. The posterolateral columns were demyelinated with proliferation of astrocytes in the demyelinated parts. Collections of fat phagocytes occurred in the lateral columns. The dorsal columns were undamaged. Loss of nerve cells was observed in the anterior horns, more marked on one side.

T.5, L.3 (fig.1). The fifth thoracic and third lumbar segments also presented demyelination and gliosis of the posterolateral columns. The vessels in the demyelinated zones had slight collagenous thickening of the adventitia, which contained some small round cells. Outside the vessel walls occurred collections of fat phagocytes. The grey matter did not present any obvious structural changes.

Clinico-pathological Correlation

Both extensor plantar responses and the right spastic weakness are attributable to the damage in the crossed pyramidal tracts. The urinary disturbance can be related to the lesion of the posterolateral columns. The numbness of the right lower limb and the more general impairment of pain and temperature appreciation can be correlated with damage in the spinothalamic tracts. The posterior nerve roots in the cervical region showed no histological evidence of injury. Therefore the numbness of the hands cannot be attributed to damage to posterior nerve roots unless one is willing to postulate a functional impairment without histological evidence of damage. This numbness may be related to the lesions of the dorsal horn, the dorsal columns and the spinothalamic tracts. The ataxic gait may be due to injury to the spinocerebellar tracts and the dorsal columns. The wasting of small hand muscles is mirrored in nerve cell loss in the anterior horns of the first thoracic segment.

Case 4.—Summary of Clinical Course

F.H., a man aged 45, was admitted to the National Hospital, Queen Square, under Dr. Risien Russell's care in June 1927 with a one-year history of weakness and numbness of his legs and more recent numbness of both arms. On examination he had a right spastic hemiparesis. He improved and was discharged. In 1938 the leg weakness recurred. He died in 1944 following prostatectomy.

Detail of Clinical Features

Nothing significant was obtained from the family history. One year before his admission in June 1927 the patient noticed a sensation like an electric shock in both legs on stooping and coughing. His legs gradually become weak and numb. The numbness extended gradually up to subcostal margin. Walking became very difficult. For a few months preceding admission he had a numb feeling in both arms radiating upwards from his hands. In January 1937 he consulted Sir James Purvis Stewart who arranged for a cisternal myelogram at the Westminster Hospital. The lipiodol was partly held up at C.6 for twenty-four hours but had completely disappeared from the cervical region in forty-eight hours.

On examination in the National Hospital he had loss of power in both lower limbs, more on the right. Tone was increased in the lower limbs. Vibration sense was absent over both tibial malleoli and appreciation of passive movement was impaired in the right toes. The tendon reflexes in the upper limbs were active and equal. The abdominal reflexes were absent. His ankle and knee jerks were very active. The right knee-jerk was brisker than the left. Ankle clonus was present bilaterally. The right plantar response was extensor and the left equivocal.

The cerebrospinal fluid on lumbar puncture was clear and colourless and contained 7 small monocytes per c.mm. The protein content was 90 mg. per cent and the Pandy reaction was positive. The Lange curve was 0000001000. Wassermann's reaction of both the blood and cerebrospinal fluid was negative.

He was treated palliatively and discharged on August 17, 1927, somewhat improved. In 1938 he again consulted Dr. Risien Russell, complaining of recurrence of weakness of the lower limbs and of pain at the bottom of his spine. In 1942 he had a period of urinary frequency followed by retention and required catheterization for one month. After this he had recurrences of frequency and then retention about every third month.

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In August 1944 he was admitted to another hospital. *On examination* he had a slight paraplegia. The abdominal reflexes were present and equal. The knee and ankle jerks were very brisk with bilateral ankle clonus and knee clonus on the right. The plantar responses were thought to be flexor and no sensory loss was reported. A prostatectomy was carried out in September. He developed thrombophlebitis of the right saphenous vein on October 3, 1944, and died three days later.

The post mortem examination was performed by Dr. Greenfield. The disc between the seventh cervical and first thoracic vertebræ was widened and protruded into the spinal canal. The cord showed loss of substance, especially on the anterior surface of the lower half of the eighth cervical segment. The ventral roots of that segment were atrophied.

Summary of Histological Changes

Demyelination and loss of axons occurred in the anterior parts of both dorsal columns and ventral to the anterior horns of the eighth cervical segment. At this level the posterolateral columns showed similar changes, to a much greater degree on one side. Chromatolysis and neuronophagia of some nerve cells were observed. The anterior nerve roots of this eighth cervical segment were thin and showed loss of axis cylinders. Gliosis was present in the damaged regions. The vessels in the cord had marked collagenous thickening of the adventitia.

Detail of Histological Changes

C.8. The upper end of the eighth cervical segment was cut transversely. It showed demyelination and axon loss of the anterior parts of both dorsal columns and in the posterolateral columns, where it was much more severe on one side. The myelin sheaths and axons about these zones were swollen. The compressed lower part of the segment was cut longitudinally (fig. 9). The anterior nerve roots were thin. Silver preparations demonstrated loss of many axis cylinders. By contrast, the posterior nerve roots were much stouter and did not appear deficient in axons. Demyelination, axon loss and reparative gliosis had occurred ventral to the anterior horns and in the anterior part of the dorsal columns. Marked proliferation of astrocytes and a thick feltwork of glial fibres were seen in the anterior grey horns where some of the nerve cells were undergoing chromatolysis and neuronophagia. The blood vessels in the cord showed marked collagenous thickening of the adventitia (fig. 10). Around the blood vessels in the anterior commissure and anterior horn were nerve fibres covered by cells of Schwann. A tangle of similar fibres and Schwann cells was present in the white matter ventral to the anterior horn.

Clinico-pathological Correlation

Clinico-pathological correlation is difficult in this case since the sections through the severely damaged regions of the cord were almost all longitudinal and did not provide much information about the lateral part of the cord. The spastic paraparesis and part of the urinary difficulty can be correlated with the damage in both lateral columns, while the decrease in vibration sense is attributable to the destruction in the anterior part of the dorsal columns.

Additional Histological Observations of Note

In Cases 2 and 4 collections of nerve fibres, demonstrated by silver impregnation methods, occurred along the vessels in the anterior median fissure, the anterior commissure and in the anterior horns. In Case 4 a tangle of similar nerve fibres was seen in the white matter ventral to the anterior horn. In hæmatoxylin and van Gieson preparations the fibres were clothed with cells identical with the cells of Schwann of the peripheral nerves (fig. 11).

In Case 2 the fibres occurred not only in the cervical region but also in the thoracic and lumbar parts of the cord. In this case myelinated nerve fibres were present around the anterior spinal vein at the first thoracic segment. The origin of these nerve fibres has not been traced in these two cases.

Discussion

Clinical Features

Sex, age of onset and trauma.—The three men had symptoms beginning in the fifth decade while the one woman was in her seventh decade at the onset of her illness. A history of trauma was not elicited in any of these cases.

Symptomatology.—Weakness of one leg, sometimes followed by weakness of the other lower limb, was a common feature, and in 3 of the cases was followed by a decrease in power of the ipsilateral upper limb. 2 of the patients complained of fear of or actual giving way of a lower limb. All 3 male patients had complaints about urination. In 2, these urinary symptoms, namely hesitancy and retention, were related to the spinal cord lesion. The third case had urinary frequency and intermittent retention for which a prostatectomy was performed. It is probable that his urinary difficulty was in part a result of the lesion in his cord.

2 of the patients complained of numbness affecting a lower limb. Numbness of both upper limbs was present in 3 patients.

3 of the patients had dull pain in the neck, often associated with stiffness and aggravated by movements of the neck. Only Case 3 had pain, of root-like nature, in the neck and arm on coughing and extension of the neck. One patient had an electric shock-like pain in the loin on turning his head, while another had a similar sensation in both legs when he stooped or coughed. A third had a similar pain passing from neck to foot on one side of the body on coughing.

Signs.—Each of the patients on examination had weakness of one or both legs, unilateral or bilateral extensor plantar responses, hyperactive deep tendon reflexes in the lower limb and ankle clonus. Weakness of an upper limb was present in 3 cases. Wasting of the small muscles of the

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hand was found in 2 cases. Appreciation of pain and temperature was diminished over the trunk and in a lower limb in 3 patients. In one case appreciation of light touch, pain and temperature was impaired over the lower cervical and upper thoracic dermatomes.

Laboratory Tests

The cerebrospinal fluid protein content varied between 50 and 130 mg. per 100 ml.

X-rays

In Cases 1 and 2 there was fusion of the bodies of two cervical vertebræ, the second and third and the third and fourth respectively. Spondylitic changes, such as osteophytic spurs and lipping, were present in 2 cases. Myelography was performed in 3 cases and demonstrated in each interruption of the column of contrast medium in the cervical region.

Course

The first patient had been ill for one year when he died during a decompressive laminectomy. The second patient had an episode of wasting of the right hand, due probably to disc protrusion some ten years prior to the recurrence of the disability. Her death was caused by pulmonary embolism. The course of the third case was only nine months. Death was due to urinary infection secondary to retention. The fourth patient had a remittent course over nineteen years; death followed prostatectomy.

Pathology

Of the 4 cases examined, 3 exhibited a single disc protrusion at the C.3–4, C.4–5 and C.7–T.1 vertebral interspaces respectively. One with multiple cervical disc protrusions showed the greatest protrusion at the C.4–5 interspace. In this case the intervertebral foramina were all narrowed. Both instances in which two adjacent vertebral bodies were fused demonstrated disc protrusion in the interspace immediately below. Fusion may increase the stresses on the adjacent discs and thus predispose to disc degeneration.

The leptomeninges were slightly thickened and showed only occasional foci of mild perivascular round-cell infiltration. The structural changes in the most affected segment consisted of flattening of the cord and of demyelination of the lateral columns of all cases, and, in 3 cases demyelination of the anterior part of the dorsal columns. Case 1 showed demyelination ventral to the anterior horn and also exhibited loss of the axons at the posterior root entry zones and of the adjacent part of the cuneate fasciculi. Segments cephalad to the most damaged segment displayed ascending degeneration in the periphery of the lateral columns

and in the dorsal columns. In the segments caudad to the lesion descending degeneration was present in the lateral columns. The grey matter exhibited nerve-cell damage and loss which were sometimes severe. Cavitation of the grey and white matter of the compressed segment was evident in Case 1, while in Case 3, the lateral columns presented numerous perivascular collections of fat phagocytes, a condition which may precede cavitation. Gliosis had occurred in the injured regions.

The blood vessels in the affected territory were thick walled due to fibrosis of the adventitia and they were occasionally surrounded by round cells.

The damage to the posterior nerve root fibres of the most affected segment occurred in the posterior root entry zones in Case 1. The other 3 cases did not show degenerative changes in the posterior nerve roots, nor was the degeneration seen in their posterior columns in the distribution of demyelination following injury of posterior nerve roots. The anterior nerve roots of the affected segments in 3 cases were deficient in axons; the corresponding anterior horns showed loss of nerve cells. The atrophy of the nerve fibres of the anterior roots may arise from destruction of the anterior horn cells, but may also result from the injury to the nerve roots in the diseased intervertebral foramina. In Case 1 the foramina were not obstructed and the loss of anterior nerve root fibres is regarded as entirely secondary to destruction of the anterior horn cells. In other cases the nerve-cell loss may be, in part, a result of the injury to the anterior nerve roots in the foramina.

In 2 cases nerve fibres covered with Schwann cells occurred around the vessels in the anterior median fissure, the commissure and the anterior horns. A tangle of similar fibres was present in the white matter ventral to the anterior horn. Some of the fibres were myelinated. Cajal (1928) has noted regeneration of nerve fibres in the injured spinal cord in mammals. These fibres, although demonstrating an attempt at regeneration, were never found to establish continuity of injured axons. He considered that these fibres originated from the axons of the anterior horn cells with damage to either their intra- or extra-spinal portions. Cajal believed that these fibres may also have arisen from other injured axons in the white matter.

The ectopic nerve fibres demonstrated in Cases 2 and 4 are considered to be an incomplete effort at regeneration and may possibly have arisen from the damaged axons of the anterior horn cells. Regenerating nerve fibres in these cases were covered with Schwann cells which in some instances had elaborated a distinct myelin sheath. Cajal examined animals within a few weeks after the injury to the cord and noted that the regenerating fibres were not then covered with Schwann cells or myelin

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sheaths but considered that it would be of great interest to ascertain whether these fibres did become covered with Schwann cells. It is probable that in Cases 2 and 3 the greater duration of time following injury permitted the growth of Schwann cells and the production of myelin around these fibres.

The regenerative capacity of the central part of the posterior nerve root has been frequently noted in injury of the spinal cord. The fibres entering the cord were covered with Schwann cells. This has been demonstrated in man by Marinesco and Minea (1906) and by Klaue (1949), and in experimental work on mammals by Stroebe (1894), Cajal (1928) and Marinesco and Minea (1906).

Clinico-pathological Correlation

The weakness of the lower limbs, the unilateral and more usually bilateral extensor plantar responses, the ankle clonus, the hyperactive deep tendon reflexes and the urinary difficulties are attributable to the lesions in the lateral columns.

Those patients with numbness of a lower limb and diminution of pain and temperature appreciation in the lower part of the body had evidence of damage in the region of the spinothalamic tracts. In this connexion it is interesting to note that 3 cases had a history of shooting pain down the body on neck movements or coughing or stooping. This may be due to mechanical stimulation of the spinothalamic tract during actions which tend to increase the pressure of the disc protrusion on the cord. Cases 2 and 3, in which there was numbness in the hands, did not show degeneration of the posterior nerve roots nor in the dorsal column in the distribution of posterior nerve roots. This numbness may be related to the lesions of the spinothalamic tracts and the ventral parts of the dorsal columns. In Case 2, where there was impairment of light touch in the seventh cervical to the second thoracic dermatomes, it is probable that this loss was secondary to a combination of the lesions in the posterior columns and the anterior spinothalmic tracts.

Wasting of the small hand muscles occurred in Cases 2 and 3 and can be attributed to the loss of anterior horn cells in the first thoracic segment in each of these cases. In Case 1 the weakness of the proximal muscles of the upper limb is related to the loss of nerve cells in the fifth cervical segment.

Pathogenesis

The diagram in fig. 12 illustrates the distribution of the cord lesions at the level of the site of compression. It does not indicate ascending or descending degeneration. The injury principally involves the anterior horns, the lateral columns and the anterior part of the dorsal columns. The lesions

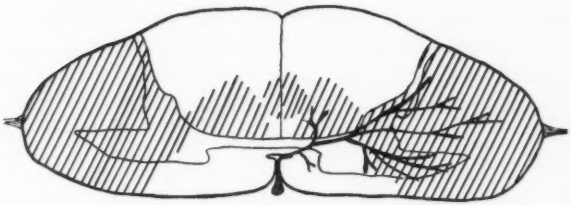

FIG. 12.—This is a composite diagram in which the shaded areas represent the distribution of the lesions in the maximally damaged segments. The anterior spinal artery and its branches are indicated.

are not of uniform severity. The less damaged portions of grey matter exhibit chromatolysis and neuronophagia, while the more severe lesions show loss of nerve cells, gliosis and even cavitation. The changes in the white matter range from swelling of the myelin and axons and microglial proliferation to destruction of myelin and axons and glial scar formation. Small cavities may occur also in the white matter as a result of tissue necrosis. The histological changes are similar to those of ischæmia.

Allen (1952) has noted pallor of the exposed cervical cord and exaggeration of the pallor upon passive flexion of the head and neck during operations on protruded cervical discs. These observations stress the importance of a vascular factor in the pathogenesis of these cord lesions. The distribution of the lesions in these four cases is, except for the sparing of the anterior columns, identical with the field of supply of the anterior spinal artery as shown by Kadyi (1889) and Bolton (1939) by injection methods, and by Spiller (1909) and Grinker and Guy (1927) in cases of thrombosis of the anterior spinal artery. For these reasons it is considered that the lesions result from reduction of blood supply in the distal distribution of the anterior spinal artery.

Kahn (1947) stressed the role of the dentate ligaments and of purely mechanical factors in the pathogenesis of spinal cord injury from herniated intervertebral discs. His theory postulated that mid-line disc protrusions would cause maximal damage to the anterior columns of the cord. In the 3 cases where the cord was examined in transverse section such a lesion was not found.

The flattening of the cord is evidence that pressure is exerted on it in an antero-posterior direction by the herniated disc. Kahn (1947) and Schneider (1951) pointed out the importance of the staying action exerted by the dentate ligaments in limiting the backward movement of the cord. The effect will be to aggravate the compression of the cord by the herniated disc. Of necessity, the anterior spinal artery must be compressed, not only on the surface of the cord, but also in its ramifications throughout the cord. The distal ramifications of the anterior spinal artery will be the most

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affected since the compressive force will exert a more marked obliterative effect upon vessels which are subjected to this force over a longer distance. The anterior columns are supplied by the proximal branches of the anterior spinal artery. These are shorter and therefore subjected to less obliterative effect. This will account for the sparing of the anterior columns. The coronal vessels derived from the anterior spinal artery will also be compressed, contributing to the ischæmia.

The compression of the vessels produces ischæmia and damage to the tissues. The blood vessels in the regions of damage have thickened adventitia, which may further slow the metabolic exchange across their walls. The onset of weakness in a lower limb before affecting an upper limb is a noteworthy feature in the first 3 cases. The motor fibres to the lower limbs are believed to lie lateral to those of the upper limbs in the crossed pyramidal tracts. The more distal situation of the fibres to the lower limbs with relation to the branches of the anterior spinal artery may explain how in compression of the cord due to protruded discs, weakness appears earlier in a lower rather than an upper limb.

It is interesting to note that Tureen (1938) postulated compression of the anterior spinal artery or its central branches to explain some of the clinical features of disc herniation.

The role played by the narrowing of the intervertebral foramina in the pathogenesis in the cases described appears to be small. The posterior roots were not atrophic in 3 of the cases, nor did the dorsal columns exhibit ascending degeneration in the distribution of the posterior roots in these cases. In the first case the compressed segment did show root damage in the posterior root entry zone and in the adjacent part of the fasciculus cuneatus on each side. This is considered to result from impairment of circulation to these regions.

Case 2 exhibited thinning of the anterior roots, together with narrowing of the intervertebral foramina. There was associated loss of nerve cells in the anterior horns. Since loss of nerve cells occurred in Case 1, which did not present any lesion of the intervertebral foramina, it may be that in Case 2 also the primary lesion was degeneration of the anterior horn cells, with subsequent loss of axons in the anterior root.

It has been suggested that the lesions in the spinal cord in cases of cervical disc protrusion are a result of venous stasis. We have no evidence to suggest that the lesion of the compressed segment was a result of venous stasis.

Summary and Conclusions

(1) The clinical features and the pathological changes in the spinal cord are presented and correlated in 4 cases of protrusion of cervical intervertebral discs.

(2) The changes in the spinal cord are considered to result from compression of the anterior spinal artery and its branches by the protruded disc.

We would like to thank the medical committee of the National Hospital, Queen Square, and Drs. D. Brinton and F. P. Meadows for permission to publish these cases. We are indebted to Dr. J. G. Greenfield for the material of Cases 3 and 4 and to Dr. W. Blackwood for Case 1, and for their encouragement in the preparation of this paper. We are grateful to Dr. H. W. Davis and Dr. J. N. Cumings for the reports on the radiological and serological investigations of Cases 1 and 2. Dr. Davis has given us permission to reproduce the myelogram of Case 1. Our thanks are also due to Miss J. Eade and Miss I. Snape for preparing the sections and Mr. J. A. Mills for his careful work in preparing the photographs.

Since preparing this paper for press, the following articles have appeared which deal with the pathological changes in the spinal cord due to protrusion of intervertebral discs:

Degeneration of the Spinal Cord associated with Cervical Spondylosis (P. D. Bedford, F. D. Bosanquet and W. Ritchie Russell), *Lancet*, 1952, **2**, 55–59; and

Thoracic Intervertebral Disc Prolapse with Spinal Cord Compression (Valentine Logue). *J. Neurol. Neurosurg. Psychiat.*, 1952, **15**, 227–241.

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PLATE I

FIG. 1.—*Case* 1 (Loyez preparations). The third cervical segment shows ascending degeneration in the posterior columns and in the periphery of the lateral columns The fifth cervical segment is flattened anteroposteriorly. Demyelination is seen in the posterolateral columns, in the lateral part of the cuneate fasciculi and in the left anterolateral column. The left anterior horn is disorganized. Descending degeneration is seen in the posterolateral columns of the seventh thoracic segment.

Case 2 (Weigert-Pal preparations). Ascending degeneration is present in the dorsal columns and in the anterolateral columns at the third cervical segment. The sixth cervical segment is demyelinated in the anterior part of the dorsal columns and in the central and peripheral parts of the lateral column. The second lumbar segment shows descending degeneration in the posterolateral columns.

Case 3 (Weigert-Pal preparations). The fourth cervical segment shows ascending degeneration in the dorsal and in the periphery of the lateral columns. The sixth cervical segment is extensively demyelinated in its lateral columns and the anterior part of the dorsal columns. Descending degeneration is seen in the posterolateral columns of the third lumbar segment.

NOTE.—Sections prepared by the Weigert-Pal method showed less shrinkage than those prepared by the ordinary techniques. This explains in part why the segments of Case 1, stained by the Loyez method, appear smaller than those of the other cases.

PLATE II

FIG. 2.—The lateral and anteroposterior views of the myelogram of Case 1 demonstrate indentation of the column of contrast medium at the level of the disc interspace between the third and fourth cervical vertebrae.

FIG. 3.—Cavitation is seen in the grey matter of the compressed fifth cervical segment of Case 1 (× 100.) (Hæmatoxylin and van Gieson preparation.)

FIG 4.—Peripheral chromatolysis of the nerve cells and astrocytic and microglial proliferation are present in the left anterior horn of the fifth cervical segment. (× 170.) (Nissl preparation.)

FIG. 5.—Fibrous thickening of the adventitia of the vessels is present in the damaged white matter of the fifth cervical segment. (× 250). (Hæmatoxylin and van Gieson preparation.)

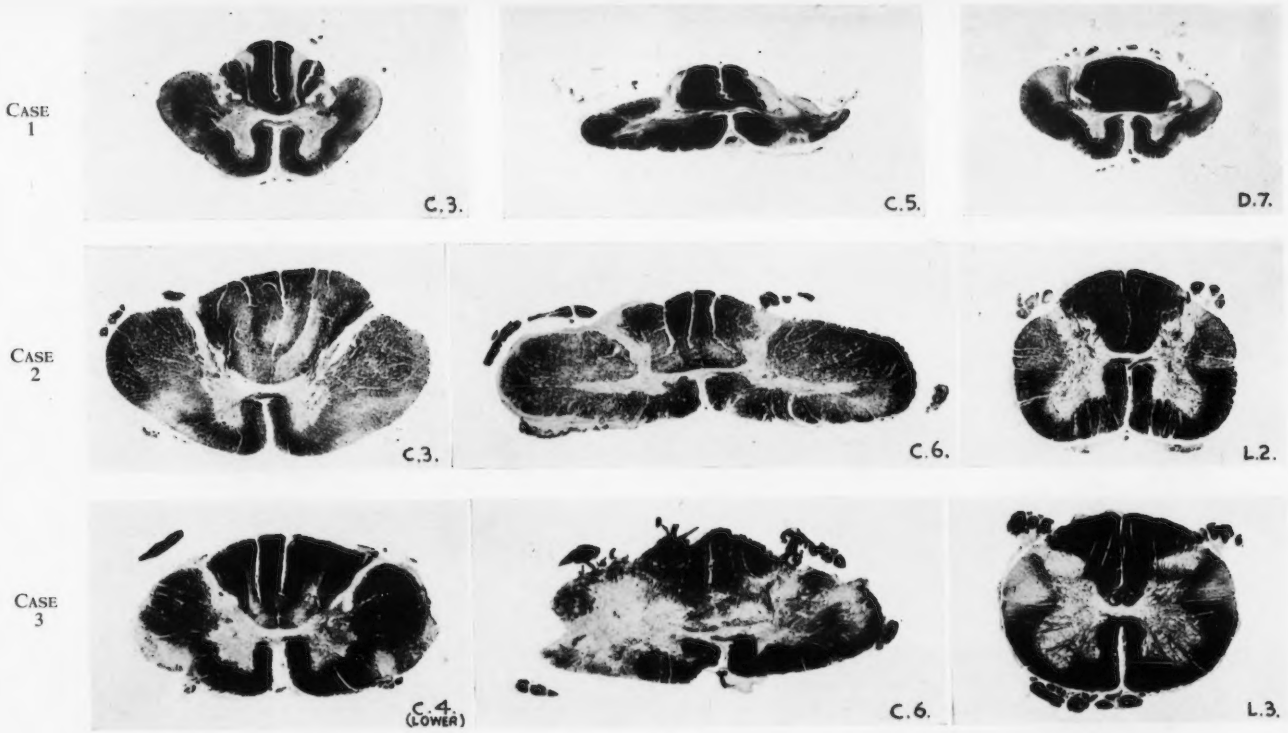

FIG. 1

To illustrate article by W. G. P. Mair and Ralph Druckman.

PLATE II

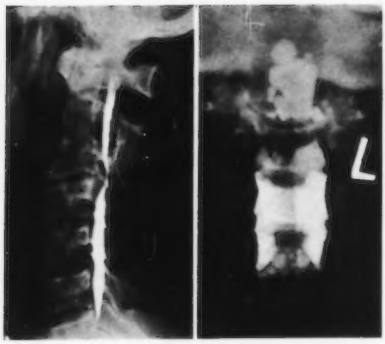

FIG. 2

FIG. 3

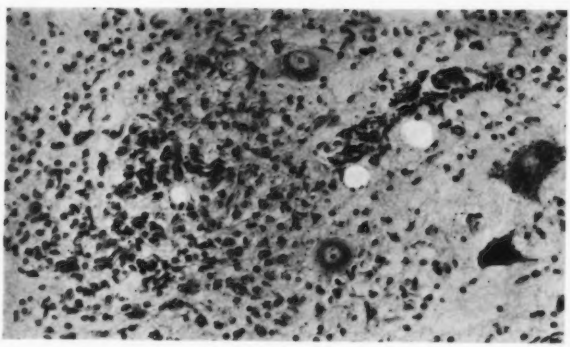

FIG. 4

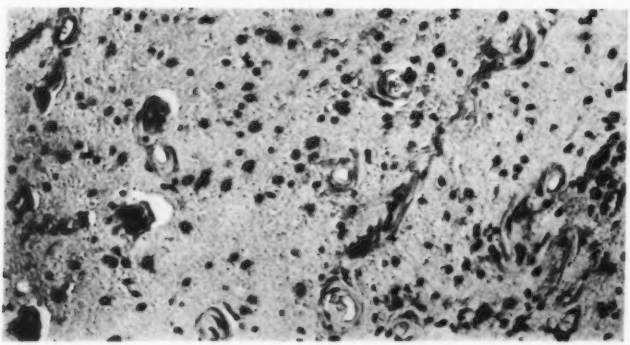

FIG. 5

To illustrate article by W. G. P. Mair and Ralph Druckman.

PLATE III

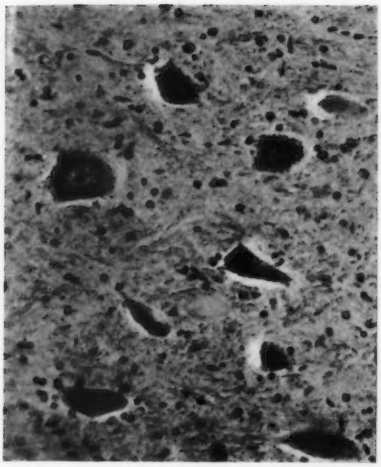

FIG. 6*a*

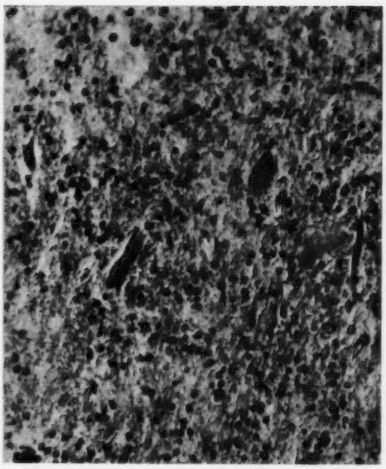

FIG. 6*b*

FIG. 7

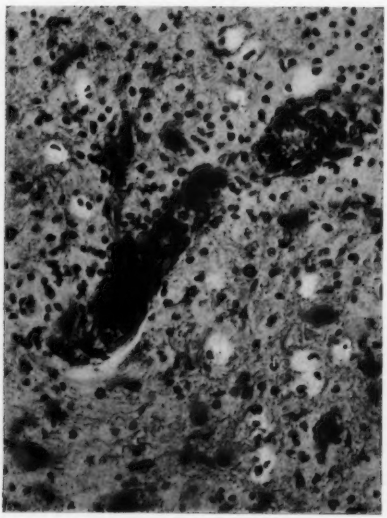

FIG. 8

To illustrate article by W. G. P. Mair and Ralph Druckman.

PLATE IV

FIG. 9

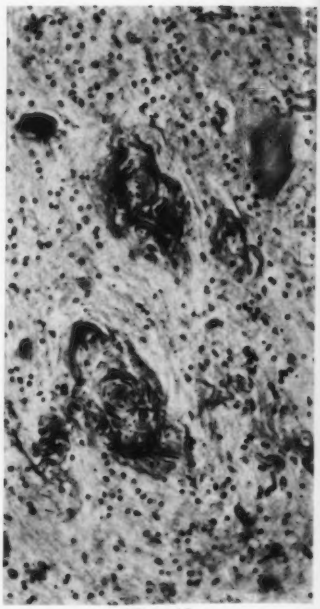

FIG. 10

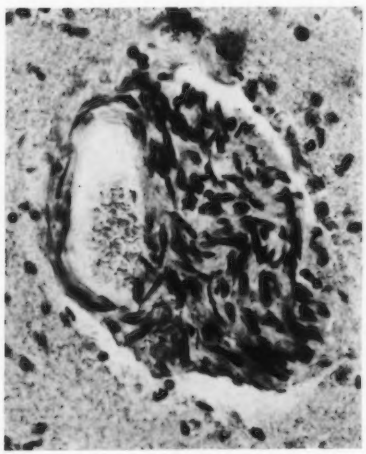

FIG. 11*a*

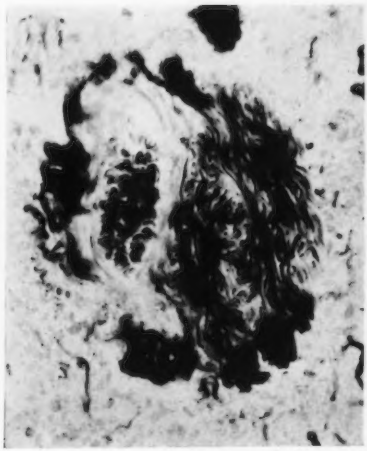

FIG. 11*b*

To illustrate article by W. G. P. Mair and Ralph Druckman.

PLATE III

FIG. 6.—*a*, A high-power view of the left anterior horn of the first thoracic segment of Case 2 shows a relatively large number of nerve cells. (× 220.) (Hæmatoxylin and van Gieson preparation.) *b*, A corresponding area from the right anterior horn of the first thoracic segment of Case 2 exhibits almost complete loss of nerve cells and replacement by astrocytes. (× 220.) (Hæmatoxylin and van Gieson preparation.)

FIG. 7.—The right thenar muscle of Case 2 shows sectors composed of normal muscle fibres and others consisting of small muscle fibres. Fibrous thickening of intermuscular septa is also demonstrated. (× 100.) (Hæmatoxylin and van Gieson preparation.)

FIG. 8.—The damaged lateral column of Case 3 shows collections of compound granular corpuscles around thickened vessels. (× 250.) (Hæmatoxylin and van Gieson preparation.)

PLATE IV

FIG. 9.—A longitudinal section of the compressed eighth cervical segment of Case 4 demonstrates the loss of axons in the white matter (V) ventral to the anterior horn (G) and in the anterior part of the dorsal column (D). The commissure (C) lies ventral to the dorsal column (D). (× 23.) (Gros-Bielschowsky preparation.)

FIG. 10.—In the anterior horn of the eighth cervical segment of Case 4 the walls of the vessels have a thickened collagenous adventitia. A nerve cell in chromatolysis is seen to the right of the upper vessel. Proliferation of astrocytes has occurred. (× 155.) (Hæmatoxylin and van Gieson preparation.)

FIG. 11.—*a*, A bundle of nerve fibres covered with cells resembling those of Schwann are present around a vessel in the anterior horn in Case 2. (× 350.) (Hæmatoxylin and van Gieson preparation.) *b*, The axons of these fibres are demonstrated by silver impregnation. (×350.) (Gros-Bielschowsky preparation.)

THE VALUE OF THE ELECTRO-ENCEPHALOGRAM IN THE DIAGNOSIS OF INTRACRANIAL TUMOURS

BY

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INTRODUCTION

THE amount of information which can be derived from the electro-encephalogram in cases of intracranial tumour is considerable. Cobb (1950) has shown in a series of 52 cases of supratentorial tumour, the pathology of which he has not specified and from which mid-line tumours are excluded, that 90·4 per cent had abnormal records and that the tumour was lateralized in 73·1 per cent and localized in 63·5 per cent.

The amount of information, however, given by a diagnostic test cannot be directly equated with its usefulness in clinical practice. In an analysis of usefulness many aspects of the test must be taken into account. Not least of these is the safety to the patient, and due weight must be given to reliability and expense. Another factor which must greatly influence the evaluation of a test is the place it occupies in a series of investigations which begins with a bedside examination and then proceeds through progressively more dangerous tests to a possible exploratory surgical operation. In this time-series a test which may render unnecessary a more dangerous procedure, or may indicate the necessity for such a procedure, has a good deal to recommend it although, otherwise, it may contribute little to the final diagnosis.

In this investigation we have attempted a further analysis of the usefulness of the EEG by dividing the information it supplies into two types, and in so doing we have recognized that the test is generally applied at some stage between straight X-rays of skull and special neuroradiological studies.

(1) The information may confirm a diagnosis which can be made on clinical evidence previously obtained, and this may be called *confirmatory* information.

(2) The information may enable a diagnosis to be made which otherwise was not possible on the basis of clinical evidence previously obtained, or may indicate the necessity for further investigation. This may be called *additive* information.

The value of these two types of information will later be discussed, and it is hoped that our results will reveal that widely differing opinions on the clinical value of the EEG are, to a great extent, compatible with each other.

Method

For the purpose of this investigation the diagnosis of an intracranial tumour is divided into four parts, each of which presents a clinical problem in itself.

(1) Are some at least of the patient's symptoms due to an organic intracranial lesion?

(2) In which cerebral hemisphere is the lesion?

(3) In which lobe of the hemisphere is the lesion?

(4) Assuming the lesion to be a tumour, is it fast or slow growing?

In each of these four problems an opinion may or may not be held, and in the former case the opinion may be held with varying degrees of confidence. In an attempt to simplify the investigation this variation has been restricted to two types—*"confident"* (based on definite clinical signs which were capable of a confident interpretation) and *"uncertain"* (based on definite or indefinite signs which were not capable of a confident interpretation).

The surgeon's opinions were recorded in the interval between straight X-rays and arteriography and/or air-studies but before the EEG records were reported. In interpreting the EEG record the electro-encephalographist was given all the clinical data available including radiological reports of straight X-rays of skull.

The method of recording the results is as follows: Each problem as defined above is represented by a box subdivided into nine squares, the horizontal rows of squares being devoted to the surgeon's opinion, and the vertical rows to that of the electro-encephalographist (fig. 1). In analysing each case it is assumed that the electro-encephalographist can express only "no opinion" on the basis of a normal record. It is apparent that in cases falling into squares 3, 6, and 9 of all boxes, the EEG gave no help to the surgeon since the electro-encephalographist had no opinion to offer. In cases in which the surgeon held *"confident"* opinions, the EEG was considered to offer confirmatory information, and such cases are shown in squares 1 and 2 of all boxes. In cases which fall within squares 4, 5, 7 and 8 of all boxes (and this group of squares is heavily outlined in the tables in the appendix) the EEG is considered to offer additive information. Cases in squares 4 and 5 are included in this since the EEG in these cases tended to diminish the surgeon's uncertainty.

The information for the investigation was abstracted from case-records and routine EEG reports and the surgeon's opinions were recorded by one of us (J. H. C.). The term "tumour" is taken to include all space-occupying lesions excluding aneurysms and with a few exceptions all cases were pathologically verified.

There is an essential difference between epileptic and non-epileptic cases as far as the EEG is concerned. In the great majority of epileptic cases an abnormal EEG record can be interpreted only as confirming the diagnosis of epilepsy or as demonstrating an epileptogenic focus. Confirming a diagnosis of epilepsy is considered, however, as equivalent clinically to distinguishing an organic condition from a psychologically determined

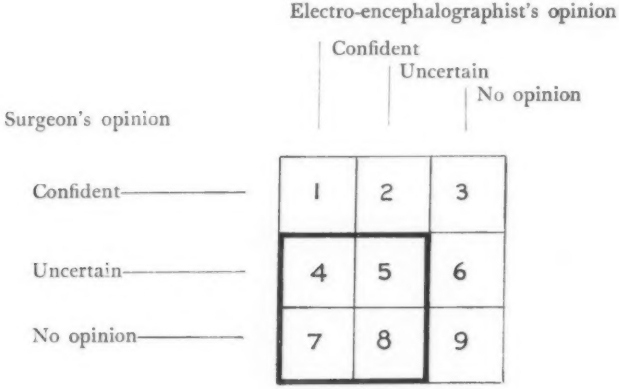

FIG. 1.

one, and the demonstration of a focus which is possibly epileptogenic as equivalent to the demonstraton of a focus which is possibly organic. Despite the difference, therefore, between epileptic and non-epileptic cases the analysis of all cases in Boxes 1, 2 and 3 is thought to be valid.

MATERIAL

Of the admissions to the neurosurgical unit only the tumour-suspect cases are considered and these cases were generally subjected to arteriography and/or air-studies. The series consists of 143 consecutive cases over the age of 16 years in which an EEG record was obtained.

Records were not obtained in certain cases treated with urgency and the series is therefore deficient in intracranial abscesses.

The cases of infratentorial tumour are such that, although the surgeon may, in some cases, have been confident of their infratentorial location, he nevertheless felt justified in subjecting his opinion to the test by the EEG.

The diagnosis of acoustic neurinomata, on the other hand, was generally so definite that they were not referred for EEG examination. For this reason it transpired that all cases of infratentorial tumour showed signs of increased intracranial pressure and this has an important bearing on the EEG results in these cases.

Aneurysms are not considered as the diagnosis is felt to depend on arteriography.

The cases are divided into five groups (total cases, 143).

(1) Tumour cases some of which had epilepsy (81).

(2) Non-tumour cases none of which had epilepsy (23).

(3) Non-tumour cases all of which had epilepsy (8).

(4) Cases of epilepsy without discoverable cause (29).

(5) Cases of headache without discoverable cause (2).

The reason for the distinction between epileptic and non-epileptic cases is given in the section dealing with method. All the epileptic tumour cases, however, showed signs of disease in addition to that of epilepsy and these cases are not divided into epileptic and non-epileptic groups. This is not true in the non-tumour group in which epileptic and non-epileptic cases are analysed separately.

The various types of pathology included in the group of tumour cases is given in Table B in the appendix.

Group 2 consists of the following cases: 7 cerebral thrombosis; 4 hydrocephalus; 1 mastoid hernia cerebri (post-mastoidectomy); 11 cerebral atrophy.

Group 3 consists of the following cases: 1 post-traumatic (? cerebral scar); 1 post-traumatic cerebral atrophy; 3 disseminated sclerosis; 3 encephalopathy of undetermined origin.

Group 4: These cases of epilepsy were suspected of having an organic basis either because of the focal nature of the fits or because a Todd's paralysis was unduly prolonged.

Group 5: These 2 cases were such that the history and description of headache raised a suspicion of an organic basis.

Apparatus

All the EEG recordings were made on a Marconi 4-channel, ink-writing instrument.

Results

The results are shown in the form of tables in the appendix and two tables which have been derived from these are shown here.

TABLE I

Analysis of the Types of Information Obtained from the EEG in Cases of Intracranial Tumour (Supratentorial 64; Infratentorial 17. Total: 81 Cases)

Information obtained from the EEG	*Aspects of the problem of diagnosis. Expressed as percentages of total* 81			
	Organic	*Lateralization*	*Localization*	*Pathology*
All types. Squares 1, 2, 4, 5, 7, 8	76 (94%)	51 (63%)	45 (56%)	6 (7%)
Confirmatory. Squares 1, 2	74 (91%)	41 (50%)	30 (37%)	2 (2%)
Additive in which surgeon had uncertain opinion. Squares 4, 5	2 (2%)	3 (4%)	10 (12%)	3 (4%)
	Expressed as % of supratentorial tumours in which surgeon had uncertain opinions			
	2 (100%)	3 (50%)	10 (66%)	3 (25%)
Additive in which surgeon had no opinion. Squares 7, 8	0	6 (7%)	5 (6%)	1 (1%)
	Expressed as % of supratentorial tumours in which surgeon had no opinions.			
	0	6 (75%)	5 (56%)	1 (4%)

This table is derived from Table A in the appendix.

TABLE II

Cases (Expressed as Percentages of the Total in Each Clinical Group) in Which Various Types of Information Were Obtained from the EEG. (Total: 112)

Types of information obtained from the EEG	*Tumour cases*	*Non-tumour cases without epilepsy*	*Non-tumour cases with epilepsy*
Total number	81	23	8
Normal	6%	22%	38%
Abnormal	94%	78%	62%
Lateralizing	63%	48%	62%
Localizing	56%	43%	50%
Pathology	7%*	0	0

This table is derived from Tables A and C in the appendix.

* The 7 per cent were thought to be fast-growing.

DISCUSSION

We do not seek to question the amount of information which can be derived from the EEG as established by other workers but it is necessary, nevertheless, that a standard of technical skill be set as a background to further discussion. By excluding the pituitary tumours and one mid-line glioblastoma from our series of supratentorial tumours (Table B, appendix), we have a group of cases which, one may suppose, is roughly comparable to Cobb's series already mentioned in the introduction. In our

series of 56 cases 94·5 per cent had abnormal records, and the tumour was confidently lateralized in 74·5 per cent and confidently located in 65·4 per cent, figures which closely correspond to those of Cobb. Such results depend so much on the selection of material that further comparisons are fruitless.

Confirmatory and additive information must each be given its own value and each may be evaluated with respect to individual cases or in terms of numbers of cases.

The value of confirmatory information, we believe, can be assessed only by individual surgeons, for the surgeon who has considerable confidence in his own diagnostic skill will gain little from an EEG record which serves only to confirm his own opinion, whereas the surgeon who is less confident will find that confirmation of his diagnosis by the EEG is, at least, reassuring. The ease with which an EEG record can be produced makes it, perhaps, an ideal means of checking a clinical diagnosis, although, unfortunately, it may rarely lend support to a wrong diagnosis, as was the case in one of our infratentorial tumours.

The value of additive information is more readily apparent. The demonstration of the side or location of a tumour, in cases in which the clinical signs are too indefinite for the surgeon to hazard a guess, reflects greatly to the credit of the EEG, and in individual cases its value is self-evident and beyond dispute. On the other hand there is room for disagreement in cases in which the surgeon holds uncertain opinions. In these cases information from the EEG, while confirming the surgeon's opinions, may help him to reach decisions about the use of special radiological methods. Before the development of angiography this was probably of some importance for the technique of ventriculography may be improved when the site of the tumour is estimated beforehand. Percutaneous angiography, however, can hardly be influenced by any information obtained from the EEG unless it be in confining the injection to one side, and to those who practise this technique with enthusiasm this may possibly be dismissed as a point of little importance. From another point of view it should not be forgotten that angiography is far from being infallible in the demonstration of cerebral tumours and the EEG could, with benefit, be employed as a check on this procedure. It may, therefore, be a matter of associated circumstances whether the EEG information, in cases in which the surgeon had uncertain opinion, should be classed as confirmatory or additive.

Since it appears impossible to evaluate confirmatory and additive information with any degree of precision in individual cases or in a manner which is generally acceptable, an attempt may be made to compare the two types of information in terms of the numbers of cases affording each

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type of information. If clinical impressions can be, at times, misleading, conclusions based on numbers of cases can be doubly so. Numbers of a particular type of case depend entirely on the selection of material and numbers, expressed as percentages of a group, can be presented in a variety of ways depending on the group selected. The selection of a group is arbitrary and in Table I we have calculated percentages on the basis of 81 tumour cases. The percentages are, of course, influenced by the relative numbers of supra- and infra-tentorial tumours but it was deemed unjustifiable to exclude the infratentorial group from the series. As previously stated, the surgeon selected infratentorial tumours for investigation by the EEG and the figures for the supratentorial group are, therefore, not indiscriminately diluted. The table reveals that confirmatory information is obtained much more frequently than additive. In respect of the latter the number of cases in which the surgeon had no opinion is very small, and, disappointing as this may seem, a judgment of this analysis should be tempered by the knowledge that this small number represents about 50 per cent of the cases of supratentorial tumours which defeated the diagnostic skill of the surgeon. The paucity of such cases is a reflection of the method of selection of cases for admission for there can be no doubt that the diagnosis of organic brain disease very often rests on the presence of focal neurological signs, a point which is made clear in Table A in the appendix.

Similar remarks may be applied to the group of cases in which the surgeon had uncertain opinions, but this group deserves further consideration. If patients are not to be subjected routinely and indiscriminately to investigation by the EEG some method of selection must be evolved and an obvious method is to select cases exhibiting equivocal signs of organic disease. In Table I it is apparent that the EEG can confirm roughly 50 per cent of doubtful cases of tumour location but our material did not allow us to analyse the value of the EEG in the solution of a more pressing problem, namely, the differential diagnosis between organic and psychologically determined conditions. The problem is easily solved when the EEG record is unequivocally abnormal but the significance of a record, which is normal or which lies in the borderland between normality and abnormality, is less easily ascertained. It is our impression that such a record is incompatible with a cerebral glioblastoma or abscess presenting with well marked clinical signs and that, for the time being at least, it would be dangerous to place upon it any further interpretation. We have learned from a study of a few cases (not included in the present series) that a large cerebral glioblastoma multiforme which gives rise only to epilepsy or minimal changes in personality or intellect, may exist in the presence of a normal EEG record, although in this type of case the rapid

evolution of neurological signs is associated with the appearance of generalized and possible focal EEG abnormalities. It would seem from this that before a normal record can be interpreted with confidence the clinician must make a close correlation between normal records on the one hand and clinical signs *and* brain pathology on the other. Unfortunately an inquiry along these lines is fraught with certain difficulties for the cases would have to be drawn from out-patient departments and observations would be required over very long periods of time.

The diagnosis of location of a lesion, in most cases, is less difficult than the diagnosis of pathology and to the latter the EEG contributes very little except in cerebral gliomata and abscesses. It might be supposed, in certain cases, that the demonstration of a focus of abnormality by the EEG should raise the suspicion of the presence of a brain tumour, yet in Table II it appears that there is no statistical basis for this supposition. As long as the problem of pathology remains unsolved it would seem that the surgeon is obliged to proceed with angiography or air-studies irrespective of any information he has previously obtained from the EEG. This lack of help in the diagnosis of pathology is probably due to the fact that investigation by the EEG is usually restricted to one recording. Serial EEG studies over a period of time may prove a means of assessing the rate of growth of tumour or of differentiating a progressive lesion from a static or regressive one. In this, as in the diagnosis of location, experience may show that serial EEG recordings will do little more than confirm impressions based on repeated neurological examinations. Nevertheless, this aspect of the use of the EEG would possibly repay careful inquiry.

The discussion thus far has centred on the tumour cases. The non-tumour cases call for no special comment except in the cases of "Epilepsy without discoverable cause." In these the demonstration of ideopathic EEG patterns must, on occasion, be ignored when the weight of clinical evidence is in favour of organic disease although, in the absence of other clinical evidence, the EEG patterns may be taken at their face value. These cases with the other non-tumour cases are included in the appendix so that the percentages in Table I may, by considering a wider group, be altered at the discretion of the reader.

To sum up, the analysis of the problem of diagnosis into four parts reveals that in lateralizing and locating tumours the EEG most often serves as a means of confirming clinical opinions (40–50 per cent of intracranial tumours) or as a means of planning ventriculography or of checking the results of angiography (12 per cent of intracranial tumours). In determining the organic nature of brain disease and the type of pathology the value of the EEG has yet to be assessed.

In ending, a comparison may be drawn between the skill of the surgeon

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and that of the electro-encephalographist in locating supratentorial tumours, excluding pituitary tumours. It can be derived from Table B in the appendix that, in terms of confident opinions, the surgeon, without the aid of special radiological studies, can lateralize 75 per cent and locate 57 per cent, while the electro-encephalographist can lateralize 73·2 per cent and locate 64·3 per cent. From what has been said above it may be concluded that this sort of comparison, although at first sight impressive, is almost without meaning and contributes nothing to the proper evaluation of the EEG in the diagnosis of intracranial tumours.

Summary

(1) Information derived from a clinical test is analysed into two types, confirmatory and additive.

(2) The value of additive information is thought to be self-evident; it is suggested that the value of confirmatory information must be assessed by the individual surgeon.

(3) The diagnosis of brain tumour is divided into four parts: organic nature of the disease: lateralization; localization; and pathology.

(4) Information from the EEG, when analysed, reveals that in lateralizing and locating a tumour the test most often serves to confirm clinical opinions (40–50 per cent of intracranial tumours).

(5) In only a few cases (6 per cent of intracranial tumours) is the information unquestionably additive, this result being related to the selection of material.

(6) In an intermediate group (12 per cent of intracranial tumours) it is a matter of associated circumstances whether the information is confirmatory or additive since this information may be used in checking the results of angiography or in planning ventriculography.

(7) It is suggested that in the determination of the organic nature of disease and the type of pathology the value of the EEG has yet to be assessed.

Acknowledgments

Acknowledgments are made to our senior colleagues of the Glasgow and West of Scotland Neurosurgical Unit for permission to use their case-records and for their helpful criticisms of this investigation. Acknowledgments are also made to Dr. Alistair Paterson, a former member of the unit, who was associated with the earlier stages of the investigation.

REFERENCE

Cobb, W. A. (1950) Electroencephalography. Edited by Denis Hill and Geoffrey Parr. London. Macdonald & Co. Ltd.

APPENDIX

The manner of tabulating the results has been described in the section dealing with method. It may be repeated here for convenience that the diagnosis is divided into four parts as follows: Box 1—Organic nature of the disease; Box 2—Hemisphere of cerebrum; Box 3—Lobe of cerebral hemisphere; Box 4—Pathology.

Group 1—*Tumour Cases*

Table A gives the total figures for supratentorial and infratentorial tumours. The supratentorial tumours are analysed in detail in Table B.

Glioblastoma Multiforme. In 2 cases the EEG record was reported as normal but one record was later considered to be abnormal. The other record was obtained from a case with a mid-line tumour giving rise only to a disturbance of personality. This type of case has been referred to in the discussion.

Secondary Carcinoma. In these cases the surgeon was confident of the pathology since primary tumours were found.

Pituitary Tumours. These cases which were demonstrated by the EEG as deep mid-line lesions are considered, for the purposes of the analysis, to be lateralized and localized.

Infratentorial Tumours. These cases are not analysed in terms of pathology. Attention is drawn to the case which was suspected clinically as having a cerebral tumour and which had a definite cerebral focus of abnormality in the EEG.

Groups 2, 3, 4, *and* 5

Non-tumour cases with and without epilepsy and cases of epilepsy without discoverable cause are shown in Table C. The cases are distributed in Box 4 in a way which is intended to indicate that the surgeon was uncertain of the presence of a tumour. In Group 4 cases are bracketed when the EEG patterns suggested that the epilepsy was of an idiopathic type. In this Group only the cases with abnormal records are further analysed in Boxes 2, 3, and 4.

Group 5 is not shown in the tables. In this group there are two cases of headache in one of which a normal air-encephalogram was obtained and in the other a normal arteriogram. In both, the EEG records were normal.

TABLE A

Correlation of Surgeon's and Electroencephalographist's Opinion

Supratentorial Tumours. Total 64

52	5	5
2	–	–
–	–	–

Box 1

35	6	9
3	–	3
5	1	2

Box 2

25	5	10
9	1	5
4	1	4

Box 3

–	2	23
–	3	9
–	1	26

Box 4

Infratentorial Tumours. Total 17

17	–	–
–	–	–
–	–	–

Box 1

–	–	7
–	–	4
–	–	–

Box 2A

–	–	–
1	–	2
–	–	–

Box 2B

–	–	–
–	–	–
–	–	3

Box 2C

Box 2A.—Surgeon thought tumour to be infratentorial.
Box 2B.—Surgeon thought tumour to be supratentorial.
Box 2C.—Surgeon had no opinion with regard to site of tumour.

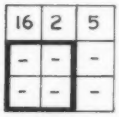
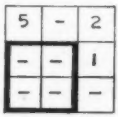
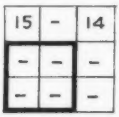
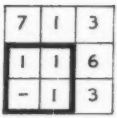
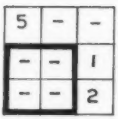
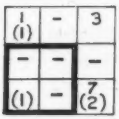
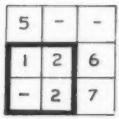
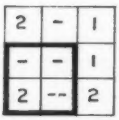
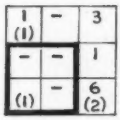
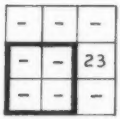
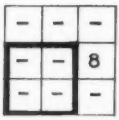
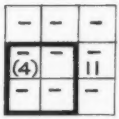
TABLE B.—SUPRATENTORIAL TUMOURS

Correlation of Surgeon's and Electroencephalographist's Opinions

	Glioblastoma multiforme	*Astrocytoma*	*Meningioma*	*Secondary carcinoma*	*Abscess*	*Pituitary*	*Miscellaneous*	*Subdural hæmatoma*
Box 1	21 – 2 – – – – – –	5 1 – – – – – – –	3 – – 1 – – – – –	8 – – – – – – – –	4 – – – – – – – –	2 4 2 – – – – – –	4 – – – – – – – –	5 – 1 1 – – – – –
Box 2	15 1 2 1 – 1 1 – 2	5 – – – – – 1 – –	2 – – 1 – – 1 – –	5 – 2 – – 1 – – –	3 – 1 – – – – – –	2 4 2 – – – – – –	2 – – – – 1 – 1 –	1 1 2 1 – – 2 – –
Box 3	11 1 3 3 – 3 1 – 1	3 – – 1 – – 1 – 1	1 – 1 2 – – – – –	3 – 1 1 – 1 – – 2	3 – 1 – – – – – –	2 4 2 – – – – – –	2 – – – 1 1 – – –	– – 2 2 – – 2 1 –
Box 4	– 2 4 – 3 5 – 1 8	– – – – – – – – 6	– – – – – – – – 4	– – 8 – – – – – –	– – 1 – – 1 – – 3	– – 8 – – – – – –	– – – – – 1 – – 3	– – 2 – – 2 – – 2

TABLE C

Correlation of Surgeon's and Electroencephalographist's Opinions

	Group 2 *Non-tumour cases without epilepsy*	*Group 3* *Non-tumour cases with epilepsy*	*Group 4* *Epilepsy without discoverable cause*
Box 1			
Box 2			
Box 3			
Box 4			

ANATOMICAL CONSIDERATIONS IN THE PATHOLOGY OF STENOSIS OF THE CEREBRAL AQUEDUCT

BY

D. H. M. WOOLLAM and J. W. MILLEN

(From The Department of Anatomy, Cambridge)

THE absence of detailed and exact anatomical knowledge of a region of the body is often an indication of the clinician's lack of interest in that part and, conversely, clinical interest in an area stimulates anatomical study in that field. Professor Dorothy Russell's authoritative monograph, "*Observations on the Pathology of Hydrocephalus*" (1949) has been largely responsible for the revival of interest in recent years in the anatomy and pathology of hydrocephalus.

The figures given by Kovats (1940) show the incidence of hydrocephalus as about 1 in 1,500 births. Walshe (1943) has stated that at least one-third of the cases of congenital hydrocephalus are due to developmental abnormalities causing obstruction to the outflow of the cerebrospinal fluid. According to Dandy (1920), half of these developmental abnormalities arise in relation to the cerebral aqueduct. It would appear therefore that the incidence of hydrocephalus due to abnormality of the aqueduct is about 1 in every 9,000 births.

It has been pointed out by Dorothy Russell (1949) that observations upon suspected cases of aqueductal stenosis should take into account the variations in the calibre of the normal aqueduct and suitable control sections should be available for comparison. She has also commented on the inadequacy of the current descriptions of the cerebral aqueduct.

The standard textbooks of Anatomy appear to take their descriptions of the aqueduct from Gerlach (1858) whose findings are at variance with the more recent study of Turkewitsch (1936). Turkewitsch, however, though giving two-plane measurements of the aqueduct at various levels, has omitted to relate these to points on the surface of the mid-brain. The most recent account of the aqueduct has been given by Beckett, Netsky and Zimmerman (1950). They have described the shape of the lumen of the aqueduct at various levels in sections taken perpendicular to the long axis of the brain-stem, but have not stated at what level a particular shape is to be found. Thus in spite of the evident importance of the aqueduct in the ætiology of hydrocephalus, there is no description in the

literature of the aqueduct which relates its anatomy to the surface of the mesencephalon, and no figures are available to indicate the normal range of calibre encountered. It has been the object of the investigation which is the subject of this communication to provide more detailed information upon the anatomy of the cerebral aqueduct, and the normal variations in its dimensions, than has been hitherto available.

Method

Fourteen brains were examined. The brains were obtained from adult patients dead from causes remote from the central nervous system. The brains were carefully examined to exclude the possibility of hydrocephalus, then fixed by suspension in a bath of 5 per cent formalin. After fixation the brains were cut down to suitable proportions, bulk-stained with carmine, and embedded in celloidin. Sections were cut at 100 μ intervals and mounted in series. The sections were magnified $\times 25$ by means of an Edinger projector and the area of each section of the lumen of the aqueduct was measured by a planimeter. From the data obtained graphs were constructed showing the cross-sectional areas of the aqueducts at 100 μ intervals and from these graphs the lengths and volumes were also calculated.

One mid-brain was stained by the Weigert-Pal method in order to facilitate the study of the relations of the aqueduct to the structures in the mesencephalon and in particular to the tectum.

Results

Most anatomical accounts describe the aqueduct as the channel connecting the third and fourth ventricles without defining its cranial and caudal boundaries. Moreover, in the literature, descriptions may be found of aqueducts, which were considered to be pathologically lengthened, that are not accompanied by any indication of the points taken to delimit the extent of the aqueduct. In view of the small dimensions of this structure in which a few millimetres may indicate the difference between the normal and the pathological, it seemed important to have a precise definition of the boundaries of the aqueduct. As no reference could be found to any attempt to demarcate these, it seemed necessary to preface any account of the normal dimensions by a definition of the extent of the cerebral aqueduct. Two considerations have decided the adoption of the landmarks used to define the limits of the aqueduct. Firstly, the aqueduct should correspond as closely as possible to the cavity of the mesencephalon in the embryo. Secondly, and this has been taken as the overriding principle, the boundaries of the aqueduct should be conveniently referable to landmarks on the surface of the mid-brain. The cranial limit of the

aqueduct has accordingly been taken as a line drawn perpendicular to the long axis of the brain-stem passing immediately caudal to the posterior commissure, and the caudal limit as a line drawn perpendicular to the long axis of the brain-stem passing immediately caudal to the inferior colliculus. Thus by this definition the aqueduct may be regarded as that part of the ventricular cavity lying ventral to the tectum. It may be described as passing from the postero-inferior recess of the third ventricle to the superior recess of the fourth ventricle.

The most striking feature of the aqueduct is the presence of two constrictions (fig. 1), one at the level of the middle of the superior colliculus and the other at the level of the intercollicular sulcus. At the caudal constriction, the lumen of the aqueduct is reduced to its smallest average dimensions. The position of these constrictions in relation to the tectum of the mid-brain was uniformly constant in all the brains measured.

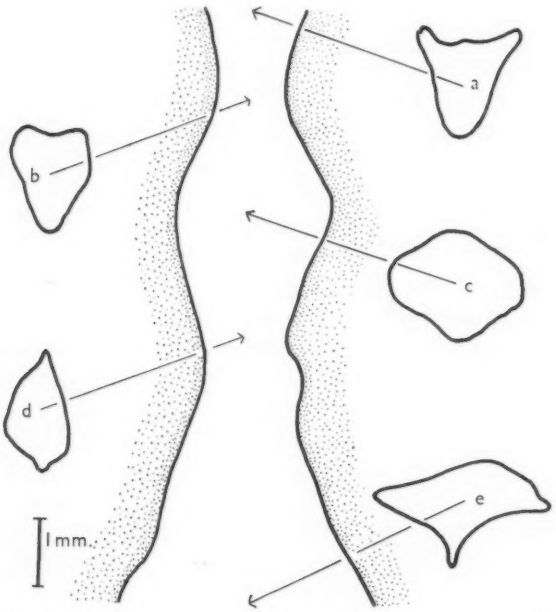


FIG. 1.—Graphic reconstruction, in the coronal plane, of the cerebral aqueduct. The shape of the aqueduct at different levels is indicated: (*a*) caudal end of posterior commissure, (*b*) middle of superior colliculus, (*c*) lower part of superior colliculus, (*d*) intercollicular sulcus, (*e*) caudal end of inferior colliculus.

The aqueduct tapers gradually from its beginning to the position of the superior constriction. Between the constrictions the lumen dilates to

form the ampulla or ventricle where the aqueduct attains its greatest dimensions. Below the inferior constriction the aqueduct widens again to join the fourth ventricle. A natural division of the aqueduct into three parts is provided by the two constrictions of its lumen. It is suggested that the part from the postero-inferior recess of the third ventricle to the superior constriction be named the Pars Anterior; the part between the constrictions the Ampulla; and the part between the inferior constriction and the superior recess of the fourth ventricle the Pars Posterior. In transverse sections taken perpendicular to the long axis of the brain-stem, the shape of the aqueduct varies widely at different levels in the individual brain-stem, though it remains remarkably constant when comparable levels are examined from different brains. The question arises as to the factors responsible for giving each part of the aqueduct its characteristic shape. The first point noted was that the shape of the peri-aqueductal grey matter bears a constant relationship to that of the aqueduct. It is impossible to resist the inference that one of the factors determining the shape and thus the dimensions of the aqueduct is the influence of the surrounding nuclear masses and fibre tracts upon the peri-aqueductal grey matter and through this upon the aqueduct itself. For example, immediately caudal to the third ventricle, the cavity is the shape of an isosceles triangle with the apex pointing ventrally. This shape may be assumed to be due to the presence of the posterior commissure cranio-dorsally and the red nuclei ventro-laterally. A little caudal to this point, the sub-commissural body causes the dorsal wall of the aqueduct to bulge forward into the cavity (fig. 2).

There is, however, another and possibly more important factor at work in determining the shape and dimensions of the adult aqueduct. At some levels in the aqueduct it was found that its dimensions were less than those seen in human embryos of 90 mm., 109 mm. and 125 mm. CR length. At these points the ependymal lining of the adult aqueduct showed marked folding suggesting that the walls of the aqueduct had been compressed inwards at some time after early fœtal life, since such folding was not observed in the fœtuses examined. Bickers and Adams (1949) have stated that the lumen of the aqueduct is greater in the third month of fœtal life than at birth. It would appear therefore that the ependymal folding may be a factor in producing aqueductal stenosis when this occurs. A study of the development of the aqueduct in man upon which the present authors are engaged may help to elucidate this point. In a brain in their possession, taken from a case of mild and asymptomatic hydrocephalus accompanied by dilatation of the aqueduct and due to blockage of the foramina of exit from the fourth ventricle, there was no evidence of the folding of the ependyma mentioned and the dimensions of the aqueduct were at all

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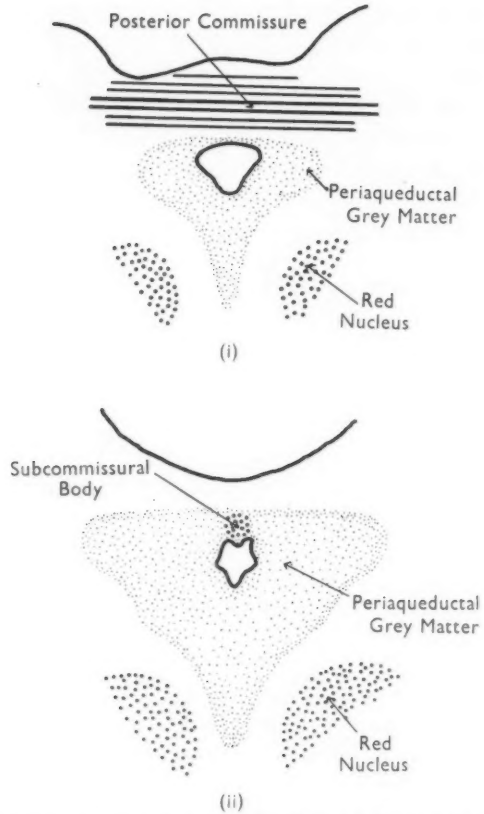

FIG. 2.—Diagrams of transverse sections through the brain-stem showing the influence on the shape of the cerebral aqueduct of (i) the posterior commissure, (ii) the sub-commissural body.

points approximately three times those normally encountered. This suggests that where the ependyma is folded it can, under the influence of increase in pressure of the cerebrospinal fluid, unfold itself and increase the dimensions of the cavity. It may be stressed that the shape of the aqueduct in this case was circular throughout the extent of the aqueduct. Not only was the greatest degree of ependymal folding found in the brains in the series with the smallest mean cross-sectional areas, but in every brain the places where the aqueduct was narrowest at either end of the ampulla showed the greatest degree of ependymal folding.

All the dimensions given are taken from brains that have been fixed, stained and sectioned. In an attempt to obtain measurements that were not

subject to the errors produced by shrinkage experiments were made with fresh and frozen brains. The diffluent nature of the brain substance, particularly noticeable in this region, produced such distortion of the aqueduct on handling that it was impossible to obtain accurate measurements. Fixation of the whole brain with a minimum of disturbance was considered to be a prerequisite to the making of a study of the dimensions of the aqueduct. While the figures obtained are subject to a shrinkage error it was considered that they provided a basis of comparison to pathologists more valuable than one based upon the examination of fresh brains.

The Dimensions of the Aqueduct (fig. 3)

The average finding is given first and is followed by the range encountered in brackets.

Length of aqueduct 11 mm. (7 mm.–12 mm.).

Length of ampulla 4·5 mm. (3·5 mm.–6 mm.).

Volume of aqueduct 11·5 c.mm. (6·5 c.mm.–16 c.mm.).

Volume of ampulla 6·5 c.mm. (3·2 c.mm.–10 c.mm.).

Area of cross-section of aqueduct 1·3 sq. mm. (0·6 sq. mm.–2 sq. mm.).

Area of cross-section at commencement of aqueduct 1·7 sq. mm. (0·8 sq. mm.–2·4 sq. mm.).

Area of cross-section at beginning of ampulla 0·9 sq. mm. (0·2 sq. mm. 1·8 sq. mm.).

Area of cross-section at middle of ampulla 1·8 sq. mm. (0·8 sq. mm.–2·9 sq. mm.).

Area of cross-section at end of ampulla 0·8 sq. mm. (0·4 sq. mm.–1·5 sq. mm.).

Area of cross-section at end of aqueduct 1·9 sq. mm. (1·2 sq. mm.–2·5 sq. mm.).

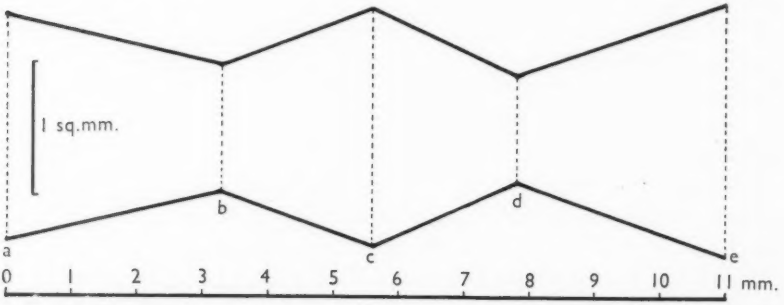

Fig. 3.—Diagram illustrating the mean cross-sectional areas of the cerebral aqueduct at different levels: (*a*) beginning of the aqueduct, (*b*) superior constriction, (*c*) middle of ampulla, (*d*) inferior constriction, (*e*) end of aqueduct.

It was found that the length of the aqueduct varied inversely as its mean area of cross-section so that the longer aqueducts in the series tended to be those with the smaller mean cross-sectional areas. On the other hand there was no significant relationship between the length and mean cross-sectional area of the ampulla, though the length of the aqueduct varied directly as the length of the ampulla. The volume of the ampulla varied directly as the volume of the aqueduct, and there was distinctly less variation in cross-sectional area in the longer aqueducts, and, conversely, the shorter aqueducts tended to show a wide range of variation in area in their course.

Discussion

Turkewitsch (1936) divided the aqueduct into five portions, a Pars Anterior, the Ampulla, a Pars Media, the Genu and a Pars Posterior. His division is based upon the study of detailed reconstructions of five brains of varying ages and he derives his points of division entirely from the internal anatomy of the aqueduct with no reference to the surface of the mid-brain. The genu is so named from the bend of the aqueduct in the lower part of its course. The genu is only apparent in a sagittal reconstruction of the aqueduct and though well marked in the brains examined by Turkewitsch is not invariably so definite. Moreover, it is not an area where the lumen of the aqueduct undergoes any marked change in cross-sectional area. For these reasons, in the consideration of a structure whose total length is some 11 mm., there appears to be little justification for an elaborate subdivision into five parts. We have therefore adopted the simple division into Pars Anterior, Ampulla and Pars Posterior outlined above.

The length of the aqueduct as given by "Gray's Anatomy" (1946) is 15 mm., by "Quain's Anatomy" (1908) less than half an inch, and by Gordiniet (1899) 20 mm. The reconstructions of Turkewitsch (1936) give a length of just over 10 mm. None of these authors have stated what points have been used in making these measurements. The reconstruction of Turkewitsch appears to take the same boundaries for the aqueduct as have been used in the present investigation and his figure corresponds most nearly to those that have been obtained.

Lichtenstein (1942) has associated the hydrocephalus which so often accompanies spina bifida with stenosis of the aqueduct, due to stretching of the aqueduct. He has given no figures for the length of the aqueduct in the cases he has described, and it is therefore difficult to fit the findings of the present investigation to the problem raised by his hypothesis. The finding that the mean cross-sectional area of the aqueduct varied inversely as the length of the aqueduct so that long aqueducts tend to be narrow may have some bearing on Lichtenstein's theory. It is possible that the

dimensions of the aqueducts in the cases he has described may be within the normal range of variation. In the present series, the cross-sectional areas in the longer aqueducts were at some levels so small that it was difficult to believe that they had come from non-hydrocephalic brains.

The shape of the aqueducts examined approximate generally to the illustrations of Gerlach (1858). There was, however, a slight variation from aqueduct to aqueduct and several aqueducts had at various levels quite uncharacteristic shapes. The small number of brains examined by Turkewitsch and their wide variation in age may have been responsible for his criticism of Gerlach's findings, a criticism which the results of this investigation do not support. The smallest mean cross-sectional area that was encountered (0·2 sq. mm.) was found at the level of the middle of the superior colliculus (the commencement of the ampulla) in one brain. Beckett, Netsky and Zimmerman (1950) have stated that the smallest aqueduct they encountered in their non-hydrocephalic series measured 0·09 sq. cm. in the microscopic section. There appeared to be some error in this figure, and when the lumen of the appropriate aqueduct in the illustrations of their paper was measured with the planimeter, it was found that the area of the lumen was 0·009 sq. cm. When the fact is taken into account that they have not indicated whether the cross-sectional area mentioned was the smallest obtainable in their case, then their figures are very comparable to those obtained by this investigation. Dorothy Russell (1949) has described a case in which stenosis of the aqueduct was associated with hydrocephalus. She has given an illustration of this aqueduct and its dimensions are not smaller than those found at several levels in the normal series described in this paper. On the other hand, at the particular level where the stenosis was said to occur in her case, the level of the inferior colliculus, no aqueduct of such small dimensions was encountered. There seems to be no apparent reason why a degree of constriction which is normal at each extremity of the ampulla should produce hydrocephalus when it occurs caudal to the ampulla. There is the possibility that a degree of obstruction sufficient to produce hydrocephalus in one brain should fail to do so in another. There is also the question whether the true relation between hydrocephalus and aqueductal stenosis is the one which is believed to exist. Lichtenstein (1942) has explained the hydrocephalus of aqueductal stenosis in spina bifida as being due to the traction exerted on the aqueduct by a meningocœle.

It may be argued equally that the stenosis of the aqueduct is produced in some cases of hydrocephalus by the traction exerted upon the midbrain by the hydrocephalic brain above. Be that as it may, when the minute dimensions of the aqueduct which serve to transmit the fluid from

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the third to the fourth ventricle are considered, the question may legitimately be asked whether the present views of the method of formation and rate of circulation of the cerebrospinal fluid should not be reconsidered.

Summary

(1) The cerebral aqueduct has been examined by means of sections and reconstructions in a series of 14 normal adult human brains.

(2) The aqueduct is defined as that portion of the ventricular cavity lying ventral to the tectum of the mid-brain and bounded by the caudal end of the posterior commissure cranially and the caudal end of the inferior colliculus caudally.

(3) The division of the aqueduct into a Pars Anterior, Ampulla and Pars Posterior is suggested.

(4) Factors influencing the form of the aqueduct are postulated.

(5) The average dimensions of the aqueduct are given and the range of variation indicated.

(6) The bearing of this information upon the pathology of hydrocephalus is discussed.

Acknowledgments

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THE NEUROLOGICAL FEATURES OF TSUTSUGAMUSHI FEVER, WITH SPECIAL REFERENCE TO DEAFNESS

BY

K. B. NOAD[1] AND WEBB HAYMAKER[2]

TSUTSUGAMUSHI fever, or "scrub typhus" as it was called during the Southwest Pacific campaigns of the recent World War, has been robbed of its terror by the introduction of chloromycetin. No medical officer who had care of patients during these campaigns will easily forget his sense of futility in the treatment of the more severe infections. Before this historic disease recedes finally into the limbo of disorders which the antibiotic age has overcome, it seemed to us appropriate to review the end results of some neurological complications of the disease, to enquire into the cause of deafness which was such a conspicuous feature, and to combine with this some observations of the lesions of nerves which appear to have escaped notice hitherto.

In the preparation of this paper a survey was made of the records of 180 Australian soldiers who had suffered from tsutsugamushi fever in New Guinea. In 106 (58·8 per cent) of these, disability had been admitted by the Repatriation Department of the Commonwealth and pensions awarded, or application had been made for pensions because of a claimed disability. In approximately 60 of the 106 (56 per cent) there were, at one time or another, discernible disorders such as the neurocirculatory syndrome, anxiety states and neurasthenia, but, at the time of writing, the symptoms ascribable to these conditions are complained of by only 40 (38 per cent) of the patients.

NEUROLOGICAL AND PSYCHIATRIC MANIFESTATIONS

Polyneuritis.—A review of the records of the early phases of the illness in the 180 cases of tsutsugamushi fever revealed that in 10 (5·5 per cent) the patients had had muscular weakness or sensory symptoms, or both, which could reasonably be ascribed to radicular or peripheral nerve lesions caused by the disease. In 9 the illness had been severe; in the tenth the degree of severity is unknown.

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The clinical features usually consisted of slight weakness and numbness of the legs with some blunting of sensation. One patient who was severely affected had had weakness of the muscles of the shoulder girdle, thigh and leg on one side, with stocking type of sensory loss in both legs. The sites implicated in 9 of the patients are indicated in Table I.

TABLE I.—MUSCLES INVOLVED BY LESIONS OF THE PERIPHERAL NERVOUS SYSTEM IN 9 PATIENTS

Shoulder girdle	3	Diaphragm	2
Shoulder girdle and lower limb ...	1	Lumbar radicular fields	1
Region of ulnar innervation ...	1	Region of external popliteal innervation	1

Examination of these patients in 1949 and onward revealed that in 9 of the 10 cases the manifestations of polyneuritis had subsided: motor power had returned and muscle bulk had been restored, but some patients have continued to complain of numbness in various areas of the body or limbs.

The one ex-serviceman who has failed to recover shows, at the time of the present writing, bilateral symmetrical atrophy of the upper half of each trapezius, and a winging of both scapulæ on testing the serrati. This condition has remained unaltered since 1944. There is no sensory loss or other neurological abnormality. Despite the appearance of symptoms on the right side in association with the attack of tsutsugamushi fever, and despite the frequency of involvement of the shoulder girdle muscles in this disease, the wasting of corresponding muscles on the left side, which began one year after the attack of tsutsugamushi fever, suggests that this case should be excluded as an example of the neurological consequences of this infection.

Convulsive seizures.—Fits during the course of the disease were not uncommon and often determined the fatal issue. They have recurred in three ex-servicemen in the group under review. The first patient had complained of blurred vision and had urinary retention during his illness. Lumbar puncture was performed, as was customary when severe headache was complained of or when the neck was rigid. The cerebrospinal fluid was normal. In this case the first convulsive seizure occurred six months after the onset of the disease. The second patient had complained of severe headache and tingling in his toes during the course of his illness. The initial epileptic seizure occurred about three months after the beginning of his illness. The third patient (A. B.) had had his first convulsive attack during convalescence from the illness, at a time when dementia and signs of an extrapyramidal disorder were also evident. Convulsions have recurred at irregular intervals in all of these patients but they have been kept well under control by anticonvulsive drugs.

The number of patients in whom the convulsive disorder developed, though small, is greater than would be expected. It would appear that the lesions of tsutsugamushi fever induced or precipitated the seizures in the third patient and may have been an ætiological factor in the other 2. No follow-up study of tsutsugamushi fever has been found which mentions epilepsy as a sequela of the disease.

Psychiatric and extrapyramidal disorders.—Although some 40 patients, already referred to, have continued to complain of symptoms generally considered psychogenic, there were 5 which merit special attention. One (A. B.) is a dement and epileptic but can be cared for in his own home. The records of this soldier indicate that he had had characteristic meningoencephalitis, as severe headache, vomiting, drowsiness and marked ptosis were noted. The Weil-Felix reaction was positive in a dilution of 1:320. After symptomatic recovery, his mental condition steadily deteriorated and was characterized by recurrent hysterical episodes. His face became masklike, his movements slow, and characteristic extrapyramidal rigidity developed in the left arm and leg. This is the only example of extrapyramidal disease following tsutsugamushi fever which we have encountered. Ripley (1946) mentioned that "acute parkinsonism" developed in one of his 50 patients.

A second patient (T. R.) suffered from a mental disorder during and after his illness, which was described by his medical officer as "exactly like G.P.I." On the twelfth day of his illness this man's behaviour was a little strange. Proteus OXK was agglutinated by his serum to a titre greater than 1:250 on the sixteenth day. He had been apyrexial for five days when, on the twenty-ninth day of illness, he had two generalized convulsions. The cerebrospinal fluid was under increased pressure and contained 1 lymphocyte and 70 red cells per c.mm., 60 mg. per cent of protein, and a chloride content of 690 mg. per cent. A grasp reflex developed in the right hand and the patient was dysphasic and exhibited constant sucking movements of the lips and tongue.

On the third day following the occurrence of the fits, the cerebrospinal fluid was turbid and under a pressure of 170 mm. It contained 138 lymphocytes and 30 neutrophils per c.mm., and 130 mg. of protein per 100 c.c. The chloride content was 710 mg. per cent. In the succeeding weeks the patient's condition was characterized by intellectual deterioration, disordered behaviour, emotional lability, and extremely defective memory. Improvement gradually took place and the psychiatrist wrote on May 29, 1944—just one year after his illness—"There are no signs of definite lesion of the C.N.S. He suffers from a degree of amnesia for present and recent events and is lacking in initiative to such a degree as to be unemployable at present."

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This ex-serviceman, a school teacher, is now teaching English and history satisfactorily at a public school. His concentration for work is good but on less important matters is still poor. His memory is defective and is worse at some times than at others. Occasionally he is moody, irritable, and depressed. While engaged in his usual routine he appears content, but expeditions to the city are still an ordeal which he will not face alone; however the over-all picture is one of great improvement and he has returned to a useful place in society.

The third patient, who was discharged with a diagnosis of "hypomania-mental disorder following scrub typhus," wrote that his health is fair, but that he suffers from headaches and giddiness and extreme irritability if upset. However he is in full employment and loses no time from work.

The fourth patient, discharged with a diagnosis of "post-infective paranoia," has made a complete recovery. His doctor wrote that he is in good health and is working full time as a council employee in one of the large country towns of New South Wales.

The fifth patient of this group died in 1948. He was considered psychopathic and had deteriorated during his army life, especially following the attack of tsutsugamushi fever. Death was due to perforation of a gastric ulcer.

Summary.—The end-results of tsutsugamushi fever contracted on service have thus been followed, in a small group of patients, for periods up to eight years after infection. The conclusions which may be drawn are as follows:

(1) The majority of those who survived the disease have made a good recovery.

(2) A small group, 3 in number, have clear-cut residual symptoms of psychiatric disorder. One of these has rather severe dementia.

(3) A small number, 3 in all, have convulsive seizures which recur infrequently and are kept well under control by anticonvulsive drugs.

(4) Those patients in whom neuritis with muscular atrophy and weakness developed have, with one exception, all made a complete recovery as far as motor function is concerned. However, some of these men still complain of sensations of numbness in the body or limbs.

(5) Approximately one-third of 106 patients (38 per cent) complain of easy fatigability, impaired energy and concentration, headache, nervousness, and breathlessness. These symptoms are grouped officially under the heading of "post-typhus syndrome" and, though motivated in a certain number for pension purposes, undoubtedly do persist in others as sequelæ of this severe and debilitating illness.

Residual Deafness and its Pathological Background

Every physician who had charge of patients suffering from tsutsugamushi fever during the recent war must have been intrigued by the deafness which occurred. Writers on epidemic typhus have also emphasized this interesting feature.

Lewthwaite (1930) described the deafness typical of tsutsugamushi fever as follows: "One such patient, whose illness was protracted by an acute bronchitis, was only slightly deaf when seen on the ninth day, and his history was easily elicited. Seen again on the sixteenth and eighteenth days, he was stone-deaf; but on the twentieth day his hearing had partially returned, and on the twenty-seventh day was again normal."

In a study of 50 patients who contracted this disease, Ripley (1946) reported deafness during earlier stages in 34. Dame (1945) studied the auditory function of 50 convalescents who had suffered from tsutsugamushi fever within four months of his examination. Half of them had complained of various aural symptoms during the first week and the proportion rose to three-quarters during the second week of illness. 15 patients complained of deafness in the first week and 24 at the fastigium. The other symptoms described were tinnitus (in 10 during the first week and in 15 during the second), pain in the ears (in 3 during the first week and in 3 in the second), and vertigo (in 3 patients at the height of their illness). 2 patients still complained of poor hearing at the time of examination, but objective tests revealed reduction of hearing in 11, though none exhibited reduced hearing to conversational tones.

Macaskill (1945), in reviewing 70 cases and describing the ocular complications of tsutsugamushi fever, wrote: "In considering the optic atrophy, it is interesting that a considerable number of cases of scrub typhus develop a nerve deafness. It is odd that this nerve should be singled out, and, as in the case of the optic nerve, the cause may be a toxic one."

The frequency of deafness during the acute phase of tsutsugamushi fever, its persistence in some cases, and the lack of knowledge as to the nature of the pathological change responsible, stimulated us to inquire into this small but important aspect of the disease by a review of the literature and of the case records of patients who had suffered from the disease, and to study the autopsy material available with a view to determining the nature of the pathological processes present in the auditory apparatus. On examining the pertinent literature, however, no account of the pathology of deafness or of the changes in the peripheral nervous system in this disorder was found.

Pathology of Deafness in Tsutsugamushi Fever

In an attempt to discover the nature of the pathological changes associated with disturbances of hearing in tsutsugamushi fever, a study was made of the brains of 16 men who had died of the disease. Most of these men were soldiers in the United States Army. Their ages ranged from 21 to 44 years. The cerebrospinal fluid had been examined in 7 cases and xanthochromia with increased protein was found in 3, but no abnormality was detected in the other 4. The only references to hearing were that deafness was noted in one patient soon after the onset of the illness (AFIP Acc. 112445),[1] and in another on the eleventh day (AFIP Acc. 112448). The clinical records contained no reference, positive or negative, to functional disturbances of other cranial nerves. This may have been due to the reluctance of the medical officers to examine the patients minutely in view of the gravity of their illness. The duration of the illness in these deceased patients varied from ten to twenty-one days, with an average of fourteen days.

Materials and Methods

As the primary object of this study was to determine the basis of auditory symptoms, the acoustic nerves were studied in every case. From each brain three or four other cranial nerves were removed, frequently bilaterally, for purposes of comparison. The auditory and vestibular nuclei were examined in each case, and the nervus intermedius in 6 cases. Also a block was taken from the mid-dorsal part of the cerebellum in each case so that the degree of cellular exudate in this region could be compared with that in the cerebellopontile angle. The diagnosis of tsutsugamushi fever in these same cases had been established pathologically by Weil and Haymaker (1946).

Nerves and blocks were embedded in paraffin and, after longitudinal section, the nerves were stained by hæmatoxylin-eosin, Masson trichrome, cresyl echt violet, and by the Bodian activated-silver method. Several acoustic nerves were serially sectioned and stained not only in the manner mentioned but also by the Wilder reticulum, the hæmatoxylin-van Gieson and the mucicarmine methods. Frozen sections were made of eight nerves taken at random and some of these were stained by oil red O and others by the Spielmeyer method for myelin and the Hortega method for axis cylinders. Sections of the brain-stem and cerebellum were stained by cresyl echt violet and hæmatoxylin-eosin.

Microscopic Examination

Leptomeninges.—The degree of cell accumulation around cranial

[1] Reference is to Armed Forces Institute of Pathology Accession Number.

nerves varied considerably and, except in a case or two, was no greater in the cerebellopontile angle than elsewhere. No predilection for the leptomeninges surrounding the acoustic nerve was found. An especially abundant cellular exudate in the vicinity of vago-glossopharyngeal rootlets is

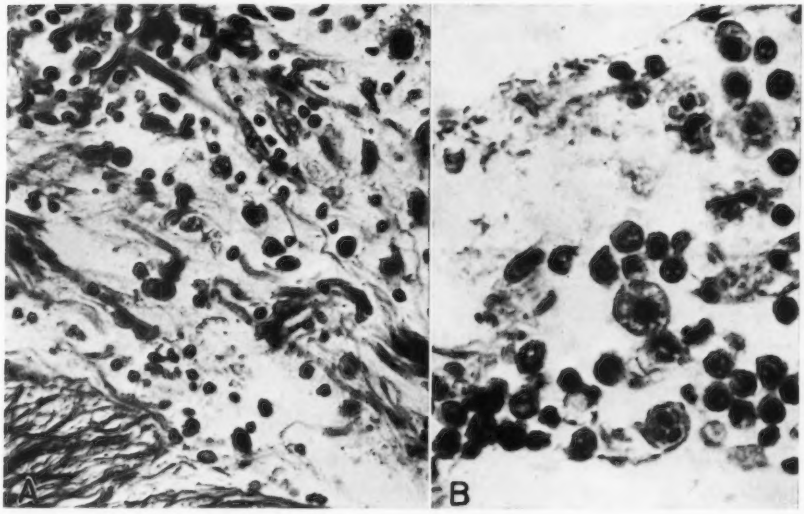

FIG. 1.—In *A* (AFIP Acc. 119275; duration ten days) are illustrated the cells in the leptomeninges adjacent to the glossopharyngeal and vagus nerves. Most of the cells are regarded as arachnoidal histiocytes in various stages of evolution. This was the largest collection of cells encountered in the region of the brain stem. × 330. Masson trichrome stain. In *B* (AFIP Acc. 112441; duration thirteen days), from the leptomeninges of the convex surface of the cerebrum, the cells are of the same type as those in *A*. ×755. Hæmatoxylin-eosin.

illustrated in fig. 1A. The cells are of the same nature as those in the leptomeninges of the cerebral cortex (fig. 1B).

The cochlear and vestibular nuclei.—Slight to moderate œdema was evident in both nuclei. A few scattered nerve cells of the cochlear nuclei showed evidence of regressive change, but similar alterations were seen in the cells of other cranial nerve nuclei. No evidence of nerve-cell degeneration of the retrograde type was observed. It is probable that little of the nerve-cell change occurred during life and that such as was present ante mortem was reversible.

Acoustic nerve and nervus intermedius.—Low-power examination of the acoustic nerve revealed that, with the exception of 4 cases, only the glial part of the nerve was included in the sections. In these 4 instances

the peripheral part was too minute to permit evaluation of its pathological status; however, distortion of myelin, such as ballooning, was found. The smallness of the peripheral part of the nerve is explicable from its anatomical relations: the glial part of the acoustic nerve, 10 to 13 mm. in length in adult males, extends across the subarachnoid space to the internal acoustic meatus, where it merges with the peripheral part either just central or just peripheral to the porus (Alexander and Obersteiner, 1908; Henschen, 1915). The glial part of the acoustic nerve displayed evidence of mild or moderate œdema in most instances. In approximately one-third of the cases there were occasional rows and scattered small foci of mononuclear cells, mainly perivascular. Vessels surrounded by mononuclear cells, presumably both hæmatogenous and arising from indigenous elements, could sometimes be followed from the subarachnoid space deep into the cochlear part of the nerve. Some of the axis cylinders adjacent to such cell groups were deformed or disrupted. Occasionally the edge of the cochlear part of the nerve was invaded by mononuclear cells from the leptomeninges; in such foci, usually minute, distortions of a few axis cylinders could be observed (fig. 2). There appeared to be no substantial difference in the degree of involvement of the cochlear and vestibular parts of the nerve.

Where fibre bundles of the nervus intermedius emerged at intervals from the acoustic nerve, their glial part was usually normal, but now and then was found heavily invaded by mononuclear cells; in such regions the axis cylinders tended to be disrupted. The peripheral part was more often and occasionally more severely affected than the glial. This was usually most evident just beyond the junction of the glial and peripheral parts where the intraneural mononuclear cells were coextensive with those in the leptomeninges. No evidence of wallerian degeneration beyond such foci was found.

Special attention was given the acoustic nerves in the 2 cases already referred to in which deafness had been experienced. Involvement was of moderate degree in both, mononuclear cells being prominent. In AFIP Acc. 112445, a few axis cylinders were focally disrupted and the myelin sheath of occasional nerve fibres showed disintegrative changes. Also there was extreme separation of nerve fibres, but whether this was due entirely to œdema could not be decided. The same degree of cell accumulation was found in hæmatoxylin-eosin-stained sections in AFIP Acc. 112448, but in this case the paraffin block containing the acoustic nerve was lost, so that no other stains could be employed.

Other cranial nerves.—Pathological changes in the glial part of the other brain-stem nerves were of approximately the same degree as in the

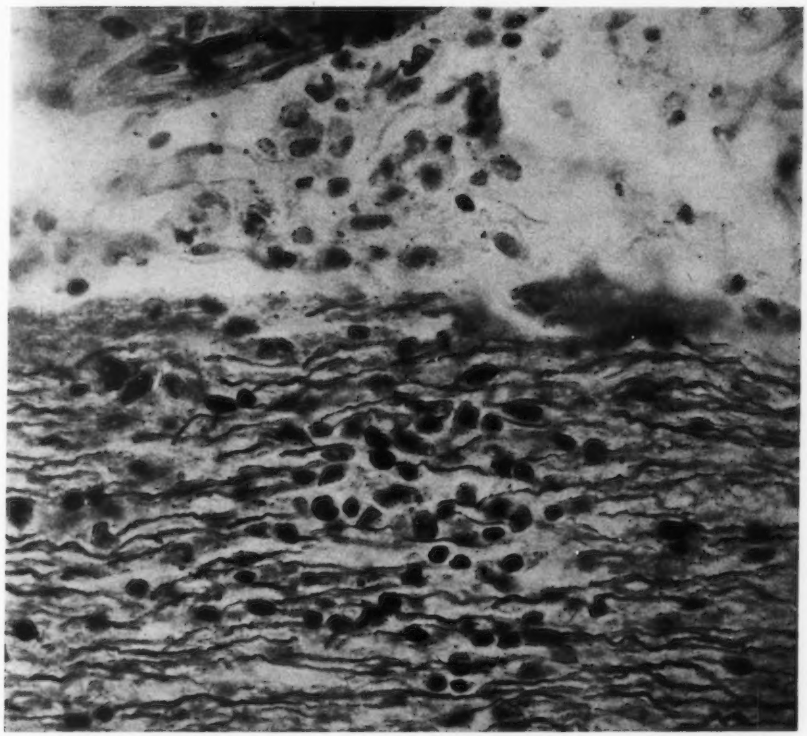

FIG. 2 (AFIP Acc. 112441; duration thirteen days).—The edge of the cochlear part of the acoustic nerve, showing mononuclear cells in the subarachnoid space and nerve. The cells in these two regions seem coextensive. A few axis cylinders are distorted. × 530. Bodian activated-silver method.

acoustic nerve. Alterations in the peripheral part of these nerves were more conspicuous. The lesions were consistent as to type, but varied in degree from nerve to nerve and from case to case. There were also indications that the duration of the lesions differed, some appearing incipient and others advanced. Considering the lesions in their entirety in each case, they were classed as mild in 7 and moderate in 9. The trochlear and facial nerves were most affected in 4 cases each, the oculomotor in 3, the abducens in 2, the vago-glossopharyngeal complex in 2, and the spinal accessory in 1. There was no difference in the severity of the lesions in proximal as compared to distal part of any of the nerves.

In most of the nerves there was generalized œdema, usually mild, and conspicuous engorgement of blood vessels (figs. 3A and 3B). In scattered areas of a few nerves tiny hæmorrhages had infiltrated groups of nerve

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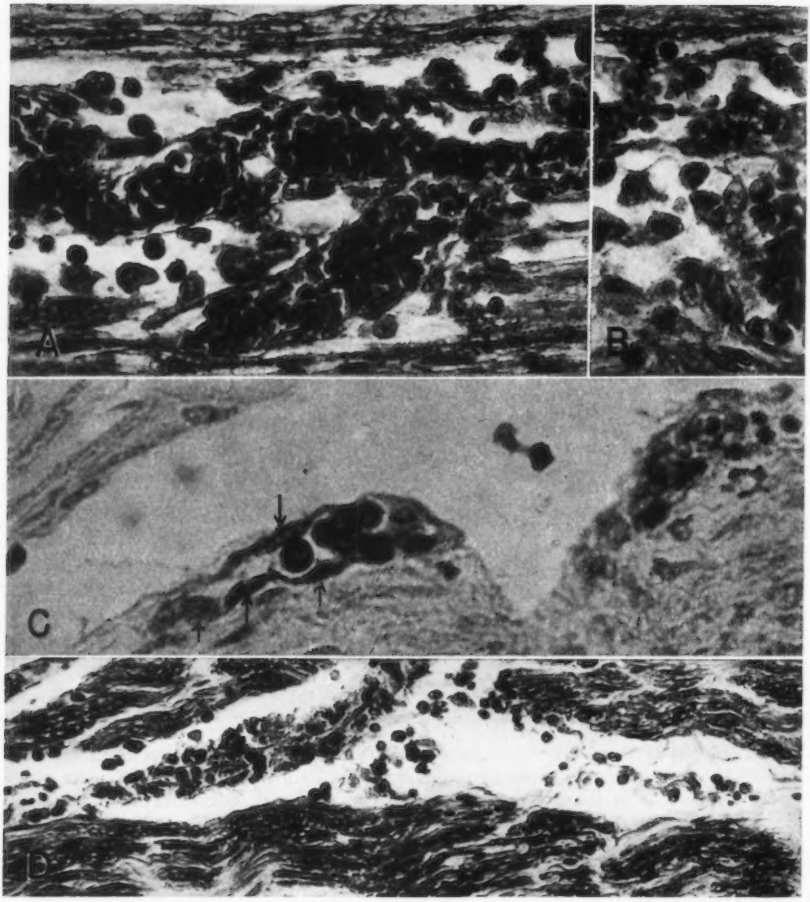

FIG. 3.—In *A* and *B* (AFIP Acc. 112445; duration eleven days), from the trochlear nerve, the vessels are engorged with blood, some endothelial cells are swollen, and mononucleur cells are congregated perivascularly. Adjacent parenchyma is little affected. *A*, × 475, *B*, × 570. Masson trichrome stain. In *C* (AFIP Acc. 119275; duration ten days), from the trigeminal nerve, the vascular endothelial cells (arrows) appear to be hyperplastic. Mononuclear cells partly fill the lumen of the vessel. × 520. Cresyl echt violet. In *D* (AFIP Acc. 119276; duration seventeen days), from the vago-glossopharyngeal rootlets, the mononuclear cells are situated in the perineurium. × 295. Masson trichrome stain.

fibres without causing any apparent damage. The endothelial cells of the vessels were usually normal in appearance, but occasionally were enlarged and rarely seemed to have proliferated (fig. 3c). No vascular thrombi

were observed. A moderate number of vessels in the epineurium, perineurium and endoneurium were surrounded by mononuclear cells similar to those found in the leptomeninges. Such collections were most numerous in endoneurial septa, but occasionally they predominated in the perineurium (fig. 3D). From their appearance, these mononuclear cells were regarded both as hæmatogenous and as arising from indigenous (adventitial) sources. The connective tissue showed no metachromasia in sections stained by cresyl echt violet.

Relatively large collections of mononuclear cells, observed here and there in about one-fourth of the cases, were often so crowded together that their borders were difficult to make out (fig. 4A)—a change seen fairly commonly in the cerebrum in these cases. In the midst of such cells myelin sheaths and axis cylinders were badly damaged (figs. 4A and 4B respectively). Such cell collections were considered to have arisen as a response to parenchymal lesions. Frozen sections of cranial nerves containing the large cell aggregates were stained by oil red O, but aside from a few small fat droplets in an occasional macrophage, no fat was seen. It should be emphasized that long stretches of nerve were free from lesions.

In addition to the larger lesions characterized by the presence of cell aggregates and destroyed myelin sheaths and axis cylinders there were small or minute foci, apparently unassociated with blood vessels, in which the myelin sheaths were destroyed and the axis cylinders unaffected.

Frequently the lesions were exceedingly minute, consisting of focal demyelination and axis cylinder deformation in an internodal segment or two of a single nerve fibre, with phagocytosis of the debris by an occasional macrophage. Such lesions are illustrated in figs. 5A and 5B. The reader will note in fig. 5B that two of the cells are labelled as Schwann cells and the third as a macrophage. All three have the clear-cut nucleolus characteristic of the Schwann cell. The latter has finely granular cytoplasm not readily visible in the photograph. One is tempted to believe that the macrophage arose through proliferation of a Schwann cell, a view expounded by Stransky (1902) and by Doinikow (1911), with which Plenk (1934) concurred, although he was of the opinion that what is generally called a Schwann cell is actually of mesodermal origin. In this connexion, Bielschowsky (1935) wrote: "Wir leiten heute die Körnchenzellen von den Schwannschen Zellen ab, die hier die gleiche Rolle spielen wie die Gliazellen bei Zerfallsvorgängen im Gehirn und Rückenmark" (p. 151). The same would apply to the cell labelled as a macrophage in fig 5A.

Lesions of presumed similar nature but much more severe and occupying relatively long stretches of a nerve fibre are illustrated in fig. 5C. Here there are long rows of macrophages among which fragments of axis cylinders can be made out. Such a picture was relatively uncommon.

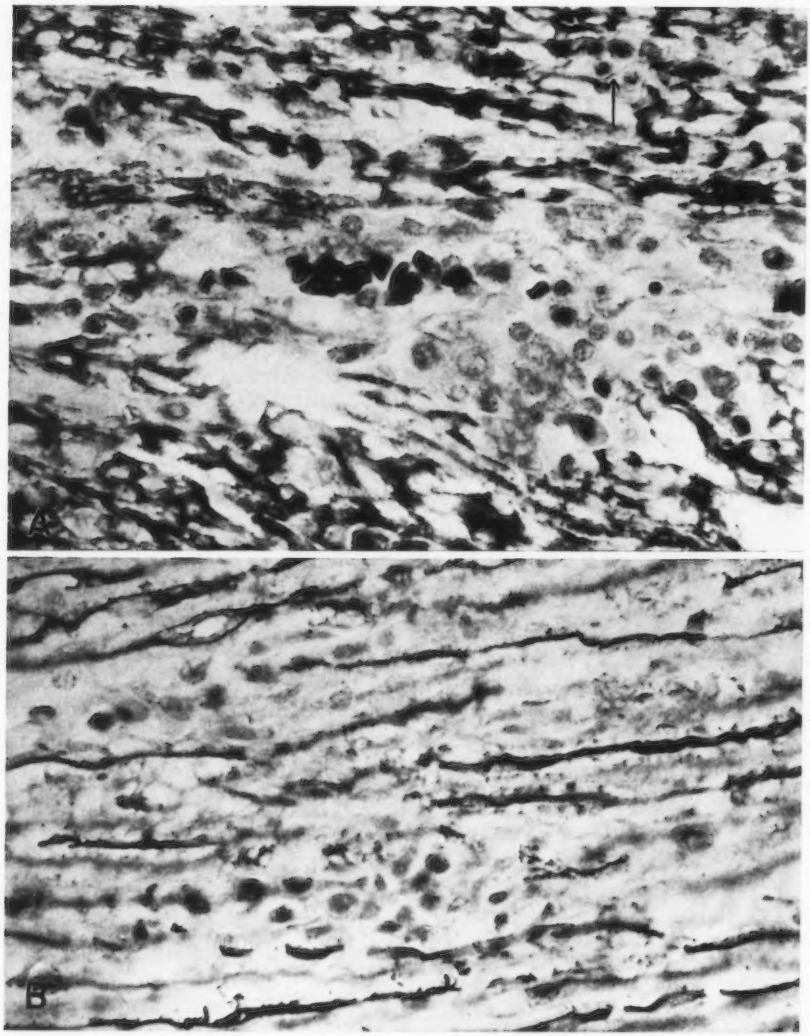

FIG. 4.—In *A* (AFIP Acc. 119265; duration fifteen days), from the oculomotor nerve, there is a relatively large cell aggregate which has replaced the parenchyma. Adjacent nerve fibres exhibit disintegrative changes in the myelin sheath. The clump of very darkly stained cells are erythrocytes. A small group of mononuclear cells (arrow) are presumably macrophages within Schwann tubules. × 720. Masson trichrome stain. In *B* (AFIP Acc. 119280; duration twenty-one days), from the oculomotor nerve, many of the axis cylinders are destroyed. There are numerous mononucleur cells. The fine plexiform fibrils in the upper left part of the photograph are believed to represent a separation of neurofibrils, not regeneration. × 720. Bodian activated-silver method.

FIG. 5.—*A* (AFIP Acc. 119274; duration eleven days) and *B* (AFIP Acc. 119275; duration ten days) are both from the facial nerve. In both, a single nerve fibre is damaged and the debris is being phagocytosed by a macrophage (M). In *A*, the axis cylinder (single arrows) can be followed from left to right beyond the macrophage where it had ruptured (2 arrows). In *B* the axis cylinder to the left (1 arrow) is intact as it approaches the node of Ranvier (N) and its vacuolated silhouette is to be seen to the right of the macrophage. In the region indicated by X the axis cylinder has a normal appearance, and further to the right it rapidly leaves the plane of section. Proliferated Schwann cells (S) and a macrophage (M) are indicated. *A*, × 750; *B*, × 650. Masson trichrome stain. In *C* (AFIP Acc. 112445; duration eleven days), from the trochlear nerve, mononuclear cells are lined up along the course of individual degenerated axis cylinders, fragments of which are indicated by arrows, × 450. Bodian activated-silver method.

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Short or long rows of macrophages were occasionally scattered through the entire cross-sectional area of a nerve. Axis cylinders encompassed by such rows were, so far as we could determine, destroyed, and yet proximal and distal to the macrophages an intact axis cylinder fully clothed by an

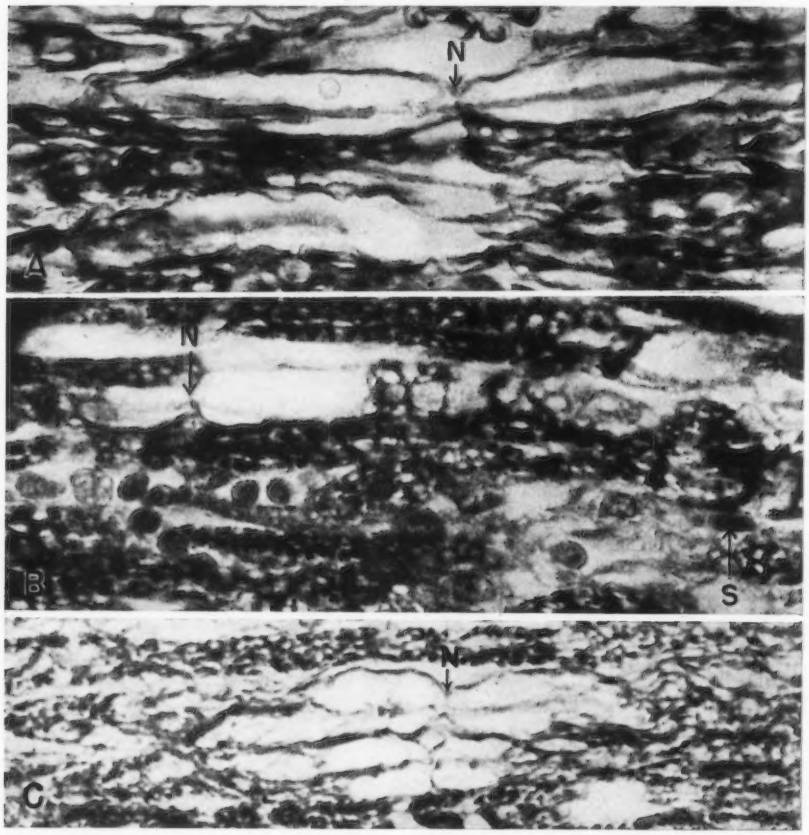

FIG. 6.—In *A* (AFIP Acc. 119274; duration eleven days), from the abducent nerve, an axis cylinder is frayed, especially in the region of the node of Ranvier (N). The myelin sheath has disappeared. No macrophages are visible. × 820. In *B* (AFIP Acc. 112435; duration twelve days), from the trochlear nerve, the picture is similar except for the fairly sharp border of the undestroyed myelin sheath. A row of mononuclear cells is to be seen near-by. The axis cylinder is ruptured. S, probable Schwann cell; N, node of Ranvier. × 865. Masson trichrome stain. *C* (AFIP Acc. 510616), from the trigeminal nerve, illustrates myelin sheath denudation and deformation of axis cylinders (AC) in the region of the node of Ranvier (N), in a case of metastasis of bronchogenic carcinoma to the brain. × 700. Masson trichrome stain.

intact myelin sheath could usually be found. The fibre changes were obviously not those of wallerian degeneration. Perhaps it was too early after axis cylinder destruction for wallerian degeneration to have set in.

Not uncommon in this series were naked, frayed axis cylinders, in the vicinity of which no macrophages were visible (figs. 6A and 6B). The dissolution of the myelin sheath seemed to have begun in the region of the node of Ranvier and progressed proximally and distally throughout much of the adjoining internodal segments. It is well recognized that such changes may be observed in a variety of non-infectious disorders. An example is bronchogenic carcinoma with metastasis to the brain (fig. 6c). The resemblance to the changes in tsutsugamushi fever is apparent.

A diffuse increase in Schwann cells in a nerve bundle was occasionally visible in cases of relatively long duration. Thus, in one case of seventeen days' standing, one-third of the diameter of a small bundle of the trigeminal nerve adjacent to the leptomeninges had been converted into a collagen-rich scar containing proliferated Schwann cells; the myelin sheath had disappeared from this area, but axis cylinders were preserved. From such an observation one may assume that the lesion was secondary to local cellular exudate (now resorbed) in the adjacent leptomeninges, causing damage to the nerve through interference with blood supply.

Study of an eye in one case (AFIP Acc. 119280) revealed sufficient large mononuclear cells in the choroid to warrant the diagnosis of mild choroiditis. Retinal hæmorrhages were observed clinically, but they were not seen microscopically. The optic nerve and disc were not available.

Discussion

It is realized that in this attempt to determine the pathology of deafness in tsutsugamushi fever, the labyrinthine portion of the cochlear nerve and the end-organ of hearing have not been examined.

This study has shown that changes within the cochlear nuclei were few and equivocal, so that damage in this region as a cause of deafness seems highly unlikely.

We must next consider to what extent changes in the acoustic nerve itself contribute to the impairment of hearing. Courville (1932), in an anatomical study of the acoustic nerve, has remarked that "the glial portion is more likely the part most affected by injury and toxic or infectious agents," the reason being, apparently, that since only this part of the nerve traverses the subarachnoid space, it alone is exposed to noxious substances. In regard to other cranial nerves, however, the glial part is relatively spared, as has been repeatedly observed in such infectious

processes as tuberculous meningitis. In these cases of tsutsugamushi fever the glial part of the nerve displayed œdema, in some instances of rather marked degree, a change not greater, however, than in other cranial nerves. More significant was the focal deformation and interruption of axis cylinders in the vicinity of perivascular collections of mononuclear cells. These changes were considered to have been of sufficient intensity to have led temporarily to defective hearing.

Considering now the peripheral part of the acoustic nerve, it was not available to us in any of the cases and thus we can only speculate as to its role in the development of the deafness. Popoff (1925) has stated that the acoustic nerve is predisposed to involvement in epidemic typhus and that this is due to its greater vascularity. Whether Popoff was referring to the glial or to the peripheral part is not clear. Be that as it may, Sunderland (1950) has shown by injection experiments that the capillary network of the acoustic nerve as a whole is essentially the same as that of other cranial nerves. One needs to consider also the possibility that the deafness may have been due to swelling of the portion of the nerve lying within the unyielding walls of the internal auditory meatus, with consequent compression ischæmia and loss of function. This is a favoured view of the causation of Bell's palsy (Kettel, 1947). Were this a factor of importance, one would expect, all other things being equal, that since the facial nerve pursues a longer course in a bony canal than the acoustic, it would be affected more often and more severely than the acoustic in tsutsugamushi fever. From the clinical data available to us on the facial nerve this does not, however, appear to be the case. Nevertheless, by exclusion, irreversible damage of the part of the nerve coursing within the internal acoustic meatus, i.e. the peripheral part, is considered a likely cause of the permanent deafness encountered. The only other possible site concerned is the internal ear.

In regard to the other cranial nerves, there were instances of obvious axis cylinder destruction, as in figs. 4B and 5C. Consideration must also be given to the functional consequences of the small foci in which myelin sheaths were destroyed and axis cylinders relatively preserved, a finding so common in this group of cases. Such focal lesions were sometimes limited to an internodal segment or two. This type of lesion was described by Gombault many years ago (1880) in peripheral neuritis due to infectious (diphtheria), toxic (lead), traumatic, and other causes, and was designated by him as *névrite segmentaire péri-axile*. Lesions of this type occurring during the course of diphtheria have been regarded by Veith (1949) as due to the direct action of the toxin on the myelin sheath. That such a lesion is not necessarily the result of the action of a toxic substance is evident

from the observation of Denny-Brown and Brenner (1944), in cats, that almost identical changes (i.e. internodal disappearance of myelin with preservation of axis cylinders [their fig. 6c]) ensue as a result of moderate percussion of a nerve trunk. They considered the demyelination to be due to ischæmia. 70 to 90 per cent of the denuded axis cylinders were so structurally changed that they were impregnated unevenly with silver, but despite this change and despite the loss of myelin the functional derangement which occurred was evanescent. Whether in our cases of tsutsugamushi fever the *névrite segmentaire péri-axile* was due to ischæmia related to retarded blood flow (as mirrored in vascular engorgement) or to the direct action of a toxic substance produced by the causative rickettsial organism (*R. orientalis*) could not be determined. The latter seems the more logical explanation in view of the demonstration that *R. orientalis* produces a specific toxin lethal for mice (Smadel *et al.*, 1946). Whether the toxin has an affinity for the nervous system has, to our knowledge, not been studied, but the observations in our cases would suggest that neurotoxicity exists. The significance of internodal myelin sheath destruction without macrophage response, as seen in fig. 6A, is difficult to decide in view of the development of similar changes in non-infectious conditions, an example of which is illustrated in fig. 6c. One can be sure that the change is pathological only if mononuclear cells have been attracted to the affected nerve fibre.

Since from the pathological standpoint all brain-stem nerves—the acoustic included—were affected to some degree, it is surprising that in clinical reports the acoustic nerve is so frequently singled out as the only one affected in tsutsugamushi fever. In the series of 16 fatal cases reported herewith there was no indication in the clinical records that cranial nerves other than the acoustic were affected, and yet from the character of the pathological changes one must conclude that at least a slight degree of sensory loss or paresis existed. Either the acoustic is a site of predilection in tsutsugamushi fever—a point which has not been settled in this study—or its involvement is more readily detected clinically.

As to the patients who survived the disease six to eight years, the deafness, which was so common during the course of the fever, remains as a disability in only 9 (5 per cent) of the 180 investigated. The degree of deafness varies from slight impairment of hearing to complete nerve deafness. 5 men receive pensions of 10 to 15 per cent for their disability. 2 have more severe deafness and their disability is assessed for pension purposes at 50 per cent.

The most severe damage to hearing observed consisted of bilateral nerve deafness in one man who was the most seriously stricken survivor

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of the disease among Australian troops. In addition to the involvement of his cochlear nerves by the infection, a bilateral optic neuritis developed, with hæmorrhage and exudate into the retina and vitreous, resulting in almost complete blindness. (Ocular symptoms, it should be mentioned, are not uncommon in this disease: Dame, 1945; Macaskill, 1945.) A glimmer of vision remains in the periphery of one segment of the visual field. No improvement has taken place either in vision or in hearing. This man has overcome his disabilities in almost an epic manner. He is making pottery of high quality on a commercial scale with great success.

Conclusions

(1) Permanent deafness following tsutsugamushi fever is considered, by exclusion, to be due to irreversible changes in the internal ear or in the peripheral part of acoustic nerve, i.e. in that part of the nerve which lies in the internal auditory meatus.

(2) The transient disturbance of hearing frequently observed in the early stages of tsutsugamushi fever could reasonably be accounted for on the basis of ischæmia of the glial part of the acoustic nerve brought about by circulatory impairment; but the unavailability of the peripheral part of the nerve precluded a consideration of its role in the pathogenesis of the transitory deafness. An added factor in the impairment of hearing may have been the focal distortion and disruption of axis cylinders in the glial part of the nerve, but these seemed too few to be decisive.

(3) From the pathological standpoint, the other brain-stem nerves, of which ample were available, displayed accumulations of inflammatory cells in the midst of which axis cylinders were distorted or destroyed. Also there were myriad minute foci of myelin sheath destruction in which axis cylinders were intact although altered structurally. Damage to myelin sheaths and axis cylinders was thought to be due to a toxin produced by the causative organism (*R. orientalis*). Clinically there was no record in the 16 fatal cases described herein of any paresis or sensory change in the realm of these cranial nerves, but from the pathological changes observed it is probable that they were present in mild degree. Patients who survived were free from signs and symptoms referable to these nerves.

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THE EXPERIENCE AND DESCRIPTION OF THE HUMAN BODY

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THE present account given by natural science of mind and of mind's relation to brain is in a state of some confusion. The causes of this are threefold:

(i) The simultaneous use of two mutually exclusive philosophical theories of perception.

(ii) The general confusion in thought between the perceived body and the actual physical body.

(iii) The confusion in neurology and allied disciplines between the body-image, the body-schema, the body-concept, and the perceived body.

The following terms are to be found in many writings in neurology and allied disciplines—the *perceived body*, the *actual physical body*, the *body-image*, the *body-schema*, and the *body-image in the brain*. It is noticeable that these terms tend to be used rather loosely and indeed as though some of them were synonymous and interchangeable. As Reitman (1950) has pointed out, this leads to arguments relevant to one set of data being wrongfully transposed to provide most misleading conclusions when applied to another set, when one of the other terms should have been used. This occurs especially when the author is attempting to apply his findings to the solution of fundamental problems in philosophy. It is necessary to make perfectly clear to what these various terms refer, and in what sense they may legitimately be used. The distinction between them must first be made before any philosophical conclusions can be drawn from the evidence presented by neurological and psychiatric studies. This is especially important, as future advances in philosophy depend very largely upon the assimilation and integration of this body of evidence.

I would suggest that the term *perceived body* should be applied to the somatic sensory field. This is the spatially extended field present in direct experience whose head surrounds the observing Self and the rest of which is extended in perceptual space below the observing Self. It is comprised of the totality of all somatic sensa available to inspection (in Broad's sense

(1923)) in any one specious present.[1] Another name for it, used by Schilder (1935), is the *postural model of the body*, though it must be remembered that this term applies in the first place to the sensa derived from the proprioceptive sensory system and that the sensa derived from the skin sensibility should also be included to describe the totality of the unified system in experience that is the perceived body. The perceived body is usually miscalled the body-image or even the body-schema, and, in any case, it is nearly always confused with the actual physical body under the influence of the universal philosophy of "common sense" or naïve realism. The perceived body and the physical body are both spatially extended. As Russell Brain (1951) has said: "In our awareness of our own bodies we are directly aware of a three-dimensional object." This three-dimensional object (or, better, field) is, as I noted above, the *perceived body*. It must then possess a spatial relationship with the actual physical body. The relationship universally assumed by "common sense" is that it is coincident with the physical body. This is, however, probably a mistake, as Hutton (1950) has recently pointed out. As she says:

"The difficulty of both realists and idealists seems to arise from a confusion of the perceived body with the percipient's actual body. Because of the experienced dependency of all perceived objects upon the perceived state of the percipient's body the ability to perceive them is located within this perceived body, and the mind is thought of as being located within this perceived skull; but what is often forgotten is that this body and this skull are themselves objects of perception."

and again:

"First and foremost it is important to draw attention to the fact that a percipient's awareness of his own body is, like his awareness of other objects, based upon the occurrence of temporo-spatial patterns in his own cerebral cortex."

Schilder (1935) has also drawn attention to the distinction that must be made between the two:

". . . the empirical method leads immediately to a deep insight that even our own body is beyond our immediate reach."

The neurological and psychiatric evidence gained from a study of the "phantom limb," the action of certain drugs upon the brain, and the various clinical conditions described so extensively by Schilder (1935) (including autotopagnosia, anosognosia, achiria, allochiria, and various syndromes found in schizophrenia) suggests that the only space system of which we can be directly aware or experience—the familiar space of our sense fields —is a localized volume within the brain. In short, the perceived body should be regarded as being coincident in space with the neurone activity

[1] The body, of course, also appears as part of the visual field. The child, however, has to *learn* that this object in the visual field *represents* his own physical body, and blind people certainly possess perceived bodies. The somatic sensory field is thus the primary perceived body.

in the brain that makes up *the body-image in the brain* of the physical body. This conclusion is forced on us when we realize that we do not experience the events of the external physical world directly (as "common sense" supposes) but that our direct experience is of events taking place at one end of an extensive signalling mechanism, the other end of which is directed at the physical world. All the sense-fields of direct experience have been through a complicated process of conduction, arrangement, and processing in the brain *before* they are actually experienced: experienced visually in the form of the extended and brightly coloured visual field "out there" and "now" before the observing Self. It is a point of fundamental importance that this presented world of direct experience is a spatial world. If "the mind," in the sense of conscious mind, be taken to mean the Self and all that is within the reach of its direct and immediate experience, then mind is in extended space.

"Accepting finite mind as having a 'where' and that 'where' within the brain . . . We have, I think, to accept that finite mind is in extended space" (Sherrington, 1940).

"The physical basis of mind encroaches more and more upon the study of mind, but there remain mental events which seem to lie beyond any physiology of the brain. . . . It is a far cry from an electrical reaction in the brain to suddenly seeing the world around one, with all its distances, its colours and chiaroscuro" (Sherrington, 1950).

It should be noted that this "world around one" is the private world of each individual's everyday experience located literally *inside,* spatio-temporally inside, what is generally known as central consciousness. "Consciousness" is a most confusing word, as it may refer either (1) to the observing Self and the spatially extended world of its immediate experience, to its sense, thought, and imagery fields, or (2) in its behaviourist and clinical reference to the degree to which we can communicate with the subject. I shall use it as little as possible and then only because it has been used in certain crucial passages in the literature. If I do, I shall use it in its first sense, that is of James's "Chamber of Consciousness," as the totality of all that transpires, all sensa and events, in the perceptual space of direct experience.

Now whether Sherrington's "mental events," the appearance and behaviour of all manifold sensa in our everyday visual fields, do or do not lie beyond the electrical reactions of the brain is not immediately relevant. What is relevant is the point that Sherrington does not go on to make, and that is that the perceived body and its behaviour belong to the same world as does the visual field in "all its distances, its colours and chiaroscuro." The perceived body has its own distances and these are also present immediately in experience—they belong to the same observational and spatial system as do the distances of the visual field. If the spatial visual

field of direct experience *is* a certain brain state, then so is the spatial perceived body of direct experience. If the visual field of direct experience lies beyond any physiology of the brain, then so does the perceived body of direct experience.

"Common sense" finds it most difficult to accept a literal statement of physiological realism[1] (or psycho-neural identity, which is the current neurological theory of perception). "Common sense" has been used to thinking for many thousands of years that the perceived body quite simply *is* the physical body and that the visual field *is* the outside physical world (which is the perceptual theory of naïve realism). Nearly everybody, whatever he may state when he is theorizing about the function of the brain, continues to believe in naïve realism in his everyday life and when considering his own nature as an observer, the relation between himself and that which he observes, the precise nature of his own visual field, and the possible way in which his own brain may be functioning. In fact he manages to believe simultaneously in two mutually incompatible theories of perception. Naïve realism and physiological realism cannot both be true. If they were both true this would entail that the following proposition were also true: "This square in your present visual field □ is actually and rigorously geometrically coincident with a small portion of your own occipital cortex inside your own perceived skull." This proposition is evidently false.

The distinction between naïve realism and "critical" realism must be kept firmly in mind. Realism itself merely states that there exists a spatio-temporal world of some kind independent of our minds and that we can know something about it. Having accepted this it then becomes necessary to give an account of the relation between sense-data and material objects, or to put it another way, between experiential events and world events. Naïve realism gives one account of this relation and physiological realism, which is one form of "critical" realism, another. It is these two accounts that are mutually exclusive. Naïve realism is "a simplifying and biologically useful assumption that the relation between sensa and material objects is nothing more complicated than the relation 'being identical with parts of the surface of . . .' or something of the sort" (Price, 1952). Physiological realism, on the other hand, gives this relation thus: "all sensa are identical with parts of the *brain* and not with the surfaces of *external* physical objects." It is not the realism that is at fault in naïve realism, it is the naïvity.

This confusion has been tolerated for the following reasons:

(i) Although most people have a clear idea in their minds when they

[1] Often miscalled "physiological idealism."

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think about the neural part of psycho-neural identity, they have no very clear idea as to what exactly are the psychical events which are to be correlated with these neural events. They think about the vague and apparently non-spatial nature of thoughts, imagery and feelings and this, coupled with the associations that the word "psychical" automatically arouses in the twentieth-century mind, is enough to confuse the issue. The most important psychical entities that must be correlated with neural events are, however, the visual field and the perceived body, which are both spatial entities—definite and not vague. Most people accept physiological realism to account for their own thoughts and feelings, which can be located within the perceived body, but continue illogically and almost unconsciously to believe in naïve realism when considering their own perceived bodies and their own visual fields.

"When, on a common-sense basis, people talk of the gulf between mind and matter, what they really have in mind is the gulf between a visual or tactual percept and a 'thought'—e.g. a memory, a pleasure, or a volition. But this, as we have seen, is a division within the mental world; the percept is as mental as the 'thought' " (Bertrand Russell, 1948).

(ii) The second means that has been used to maintain a belief in naïve realism at the same time as the clear demonstration by physics and neurology that the immediate antecedent condition of any sensation, including a body sensation, is a certain brain state has been the concept of "projection." A stimulus affecting a sense organ sets off a signal travelling up a sensory nerve to the brain where certain complex changes take place. Until these have taken place no sensum whatever is experienced. It is alleged that when the appropriate sensum is experienced it is "projected" to the site at which the original stimulus was applied or that from which the original light or sound wave started. No explanation has ever been given as to how this alleged "projection" is effected nor of the physiological processes involved. There is a whole series of complex mechanisms which evidently conduct the stimuli to the brain but no trace of any mechanism to take the stimuli back to their place of origin. Consider, for example, the current scientific account of looking at Sirius. The beam of light leaving Sirius must travel for many hundreds of years through outer space at a great velocity before penetrating the transparent cornea and lens and striking the retina. Then an incredibly complicated series of electrochemical changes is set up in the most complex mechanism of the universe. These conduct the pattern of the event to the occipital cortex where it forms one of an ever-changing flux of electronic patterns shimmering through the electrical circuits of the brain in time. The brain has only one obvious output—the motor outflow—the impulses down which are deter-

mined by the total state of the brain, to which state the incoming stimuli set up in the organism by the beam of light from Sirius made their small contribution. This story is complete in itself. There is no room in it for any process of "projection," which, it must be noticed, must travel *backward in time* as well as outward in space. The more one considers the complex nature of the visual and other sensory fields and the evidence as to the manner of their presentation (after-images and the stroboscopic patterns supply part of this evidence) the more it becomes apparent that this alleged "projection" is a mythical process. Why, then, is this process almost universally and almost unconsciously assumed? Because it is very evident that the little twinkly sensum that is our direct experience or view of Sirius is geographically *outside* the confines of the *perceived body*. "Externality is the cardinal problem" (Russell Brain, 1951). If, however, the perceived body is identified with the *body-image in the brain*, it is no longer necessary to depend upon mythical processes. This change in thought must be effected in the face of the instinctive protestations of our ingrained naïvely realistic unconscious presuppositions. It is, however, the main task of natural science to examine critically the system of assumptions it has inherited from "common sense." We may now recognize that both the little twinkly sensum which is at the proximal end of a causal chain that started some hundreds of years ago at Sirius, and the mass of the perceived body, which is at the proximal end of a causal chain that started a few fractions of a second ago at the various sense organs inside the physical body, are both literally brain states and are both geographically *inside* the physical body. The necessity to postulate an imaginary process of "projection" and the problems of externality are thus avoided.

It might be argued that the brain has *learnt* by its experience to distinguish between stimuli coming from, say, the hand and those coming from the foot, and between both these and those coming up the optic radiations from the retinæ. The process of subsequent recognition may then be supposed to give rise to the appearance that these stimuli lie outside the brain, in the physical hand and foot and in the outer physical world respectively. This, however, merely transposes the mystery from a process of "projection" to one of "creating an appearance of." While there is little doubt that the brain mechanisms have to learn to transmit the patterns to the visual field (Young, 1951), yet the visual field is a definite structure (viz. the interior of part of a hollow sphere (Price, 1950)) and we have direct evidence from the stroboscopic patterns and after-images of the manner of the presentation of visual sensa. This does not suggest any process of "creating an appearance of" but rather that we are inspecting the events at the proximal end of a television-like signalling mechanism. Certain

neurophysiologists have suggested (Grey Walter, 1950) that the brain mechanisms concerned with vision do in fact function along lines similar to television. The evidence presented, the nature of the visual fields, and the nature of the stroboscopic phenomena[1] certainly make this hypothesis an attractive one. If we examine our sense-fields as they present themselves to direct inspection, it is perfectly possible to imagine that all this is being presented continually by a mechanism something like television. There are, however, certain fundamental features of the television process, the most important of which is that it will not present the witness with a direct view of the events "televised." We witness a representation of these events *constructed* by the television mechanism. The events on the television screen are *determined* by the events in the television studio by means of the signalling mechanism in between, but they are quite different events located in quite a different part of space. There is no reason why the brain mechanisms should be exempt from this general rule. It is inadequate merely to postulate a television-like mechanism in the brain, or to suggest that the brain is an organ for handling signals. This mechanism and these signals must be capable of presenting the spatially extended and brilliantly coloured visual field as this appears in actual experience—"the world around us with all its distances, its colours and chiaroscuro"—together with our actual experience of the processes underlying the manner of presentation—after-images and the stroboscopic phenomena. It must also be able to construct the perceived body and to present sounds as heard. It is the function of science to indulge in the rational correlation of experience (Dingle, 1937) and not to ignore it.

There must be, however, a certain amount of projection of a different sort entailed in the presentation of the visual field. It seems possible that we may get a better notion of the actual structure upon which the visual field in central consciousness is presented by examining the field in which after-images and the stroboscopic patterns are located. I have dealt with this question in more detail elsewhere (1951).

The perceived body is thus not the same *thing* as the physical body. The spatial interrelations of parts of the perceived body reproduce those of the physical body because there is a system of signalling mechanism between the two. When this signalling mechanism goes wrong, as in certain brain lesions, in mescaline intoxication, and in schizophrenia, the behaviour of the perceived body may be quite different from that of the physical body, but follows exactly the state of the body-image in the brain.

[1] The stroboscopic phenomena are the directly experienced sensory patterns witnessed on looking at a flashing electronic stroboscope.

"We have shown clearly that the postural model of the body is often different from the actual position in which the body is. It is clear that in pathological conditions the discrepancy between the postural model of the body and its actual position may become still greater. To put it briefly, we may say that many of the tonic changes in the posture of the limbs change the actual body only and not the body-image" [by body-image Schilder means in this context the perceived body] (Schilder, 1935).

The burden of naïve realism lies heavily upon the science of perception. It leads Schilder to the following remark (1935):

"Vestibular experiments and observations of amputated people have shown that every body contains in itself a phantom (perhaps the body itself is a phantom) in addition."

The phantom is merely the familiar perceived body which usually follows faithfully every move and state of the physical body by reason of the signalling mechanism between the two. In disease states, when this following is deranged, it becomes apparent that the perceived body is different from the physical body—it possesses an arm, for instance, while the physical body does not—and the notion of a "phantom" arises.

In naïve realism the Self is identified with the mind, and the world of direct experience with the outside physical world. The evident facts that the perceived body and the extended visual field are extended structures in central consciousness, and that perceptual space is not precisely the same entity as physical space, are not realized.

"All this, I say, has long been a commonplace, but it has a consequence that has not been adequately recognized, namely that the space in which the physical table is located must also be different from the space that we know by experience" (Bertrand Russell, 1948).

Bertrand Russell in "Human Knowledge" gives a clear exposition of physiological realism and the way in which it must be considered to have displaced naïve realism as the foundational philosophical system of contemporary science. But I do not suppose that anyone reading this work has really appreciated the implications of this change upon our common-sense outlook upon the world. This change is brought into relief by considering the answer to the question: What is the size of the physical body relative to the perceived body? The answer is, of course, that it is very much larger. This point is clearly made by E. A. Burtt (1932). The immediate and actual surroundings of the perceived body must, therefore, be not the space outside the physical body and the objects contained therein, but brain cells and brain fibres immediately surrounding the parts of the brain containing the perceived body. The physical body, under any philosophical theory of psycho-neural identity or physiological realism, is a monstrous structure relative to our common-sense ideas of it, if this theory is applied properly and if our natural but illegitimate tendencies to

take refuge in naïve realism, as soon as any difficulties present themselves, are rigorously combated. The sensa making up the perceived body cannot be treated any differently from the sensa making up the visual field. Both have been through the same processing in the brain before they are actually perceived.

The second potent source of confusion lies in the use of the terms *body-image* and *body-schema* to describe the perceived body. These terms have their own specific meanings and refer to entities which are not clearly extended in space. If they are used to describe the perceived body, the fact that this is a spatial object is easily overlooked. It may then be merely unconsciously assumed that the space that it occupies is the same space as is occupied by the physical body. At a higher level of sophistication the mythical process of "projection" may be invoked. All these awkward subterfuges may be avoided by making the simple proposition that experiential events *are* brain events.

The term *body-image* properly describes a visual, mental or memory image of a human body, one's own or someone else's. The term (own) *body-concept* properly describes the constellation of memories and beliefs we each possess concerning our own physical bodies. We know (in the sense "wissen") matters of fact about our own physical bodies without having to make any observations of any kind. We have learnt these facts from our past experience and have remembered them. We know, for instance, that we have a left side and a right side, two arms and legs, coloured eyes, a tubular shape, etc. We know how strong we are and what actions we can perform, how skilfully we can perform them, and whether we have received any injuries that have reduced our physical capacity. The body-concept is not always accurate as it is affected by wishes and pride. It is subject to natural change as experience unfolds. This change is rapid in youth and much slower as we get older.

In cases of "phantom" limb the perceived body may possess a leg which the physical body does not. Yet the person knows (Wissen) he has only one physical leg and his body-concept is unaffected though the "phantom" will be a puzzle.

Similarly in autotopagnosia there is a pure disorder of perception (the perceived body has parts missing) whereas in (somatic) anosognosia there is a concomitant disorder of the body-concept. In both these conditions the physical body is intact and the perceived body may have one entire side destroyed by the cerebral lesion. In the former the patient will give a correct answer to such questions as "How many legs have you?" whereas in the latter he will give an incorrect answer, showing a disorder of his conceptual system referring to his own body.

Parallel to this conceptual system available to consciousness relating to our own physical bodies there is a system of *subconscious* knowledge (I use "knowledge" for want of a better word) also relating to the present and past state of the physical body. This belongs to the system called by Sherrington (1940) the "motor individual." The great system (of servo-mechanisms) responsible for posture, automatic movements and the co-ordination of voluntary movement (the activity of which goes on below the "threshold of consciousness," or, better, *outside perceptual space*, without our knowing any more about it than that our actions are carried out efficiently) also possesses its totality of information about the state of the physical body and its environment. This is the *body-schema* in the sense used by Head and Holmes (1911). They define it as being "the fundamental standard against which all postural changes are measured." When they enlarge this definition later it becomes clear that they mean it to apply to this aspect of the function of these subconscious electronic mechanisms in the brain.

"But, in addition to its function as an organ for local attention, the sensory cortex is also the storehouse for past impressions. These may rise into consciousness as images, but more often, as in the case of spacial impressions *remain outside central consciousness. Here* they form organized models of ourselves which may be termed 'schemata.' Such schemata modify the impressions produced by incoming sensory impulses in such a way that the final sensations of position, or of locality, *rise into consciousness* charged with a relation to something that has happened before." (My italics.)

It may be noticed that, taking the Self as central, the physical body is on the distal side of this charging process; that the body-schema is at the site of the charging process; and that the perceived body is on its proximal side. The experiments of Stratton *et al.* (described by Schilder, 1935) give a good example of how an almost pure disorder[1] of the body-schemata may be built up by feeding them with contradictory sensory information.

It cannot be emphasized sufficiently that, if the theory of psycho-neural identity or physiological realism is held to be true, then a man's own visual field present in his immediate experience must *literally* be an expanse constructed somehow by the mechanisms present in his own occipito-parietal or occipito-temporal cortex or cortico-thalamic connexions, and his perceived body must *literally* be located in his own parietal cortex or cortico-thalamic connexions. Thus the sensory and imagery fields of his experience must literally be made of the substance of his own brain. They must be surrounded, in physical space, by the rest of his own brain, activities in

[1] "Pure" in that there is no concomitant disorder in the perceived body, body-concept, or body-imagery.

parts of which continually and actively determine the events in his visual field and other sensory fields. These other parts of his brain form part of the most complicated signalling mechanism which lies literally between his external sense organs and his internal sense organs or sense fields. Schilder (1935) puts it thus with respect to the visual field:

"The conscious optic images and perceptions are only a small part of what is going on in the optic sphere."

If naïve realism is true the physical brain is literally inside the perceived skull, but if physiological realism is true the perceived body and skull together are literally inside the physical brain.

Since visual imagery is such a very different thing from the perceived body, and since both of these are different from both the body-schema and the body-concept, the confusion arising from a free interchange of these terms will readily be appreciated. A classical example of this confusion may be found in the opening paragraph of Schilder's book from which I have quoted above.

"The image of the human body means the picture of our own body that we form in our mind, that is to say the way in which the body appears to ourselves."

The first part of this sentence refers to a visual image of the body, or, if a more extended process is being referred to, the body-concept. The second part is full of ambiguities. What exactly does "the way in which the body appears to ourselves" mean in terms of actual experience or in terms of the processes in the nervous system and physical body postulated by the accepted theory of psycho-neural identity as lying geographically and literally outside experience? The phrase may have the following meanings:

(1) It may refer to the state of the somatic sensory field, that is the perceived body, as given in experience to direct inspection (in Broad's sense), in any one specious present, or over any one single period, or periods, of time.

(1*a*) This may be extended to include the visual sensa making up the appearance of the body in the visual field.

(2) "The way in which" may also be interpreted as "the manner in which." This would then refer to the whole complex of processes whereby states of the physical body affect the somatic sensory field, and would include the sub- or extra-conscious neurological processes underlying the presentation of experience, as well as the state of the somatic sensory field as in (1).

(2*a*) This may also be extended to the visual field (as in (1*a*)).

(3) It might also be taken to include the way in which our bodies

appear to ourselves when we indulge in thought or meditation about them. This would include the body-concept, and body-images.

Schilder continues:

"There are sensations which are given to us. We see parts of the body-surface. We have tactile, thermal, pain impressions. There are sensations coming from the muscles and their sheaths, indicating the deformation of the muscles (energy sense, von Frey); and sensations coming from the viscera. Beyond that there is the immediate experience that there is a unity of the body. This unity is perceived, yet it is more than a perception. We call it a schema of our body or body-schema, . . ."

All the sensa enumerated (except the visual) make up at any instant the perceived body. From this given unity we may abstract by our attention at any instant an individual sensum, but the unity is *given,* and is certainly not to be confused with the body-schema. Schilder goes on:

". . . or, following Head, who emphasizes the importance of the knowledge of the position of the body, postural model of the body. The body-schema is the tri-dimensional image everyone has about himself. We may call it 'body-image'."

The unity of the perceived body is not the *body-image;* nor is the body-schema the three-dimensional image everyone has about himself. The body-schema is a function of a subconscious mechanism *outside* central consciousness as originally defined. Its presence is inferred and not witnessed or experienced. The three-dimensional object given *inside* central consciousness is the familiar perceived body.

A further example of this confusion may be found in Bychowski (1943). Throughout this article he uses the term *body-image* in the sense of both *body-schema* and *perceived-body,* and when it becomes necessary to account for the space occupied by the perceived body this is then identified with the physical body. Take, for example, these passages:

"New bodily skills, acquired even late in life, modify the body-image which thus acquires new characteristics and a new differentiation."

Here body-image is clearly being used in the sense body-schema, since skills are largely subconscious. New bodily skills would modify the body-concept as well (since we would then know consciously that we were more skilful in these tasks) but not the perceived body.

"Federn has made some excellent observations and analyses of the changes that take place in the *body-image* during the stage of falling asleep. . . . Two phenomena belong especially to this group; the first are the changes in the sensory evaluation of the magnitude of particular parts of the *body*; for example, the extremities, the head, parts of the face become disproportionately large or small" (my italics).

Here both *body-image* and *body* should be replaced by *perceived body.* These observations were carried out directly on the state of the perceived body. A man does not know anything about the present state of his physical body except in so far as signals from it alter the state of the body-image in his brain.

Conclusion

We should differentiate between the physical body and the perceived body on the grounds of spatial location. The latter should be regarded as being coincident in space with the body-image in the brain of the physical body *if the theory of psycho-neural identity is held to be true.* In Broad's terminology (1923) the perceived body is a sense-field or cross-section of a sense-history. The physical body is a physical object. They are connected by Broad's formula o – R – s, in which I have suggested (1952) that R stands for connexion by signalling mechanism. The perceived body is directly experienced *inside* central consciousness. The existence of even the individual observer's own physical body is inferred. The term body-image should be reserved to describe a visual, mental, or memory image of a human body. Body-images are experienced. The constant visual imagery relating to the body and parts of the body associated with movement and sensation is integrated, largely by the subconscious system of servo-mechanisms, into the unitary function of the human organism. The term body-schema should only be used in its original sense. It is part of the subconscious mind and thus its presence is inferred. The body-concept is a conceptual constellation and depends largely upon the proper function of the relevant memory mechanisms.

Before any sense can be made in the scientific approach to the mind-body problem it is essential that everyone, when using a term, should know exactly what it means, and that other people, using the same term, should mean precisely the same thing. This applies especially to terms describing the human body as this appears from various viewpoints—to the body itself and to the small model of itself which it carries within it. Otherwise nothing but confusion can result.

> Nothing is more astonishing in the history of philosophic thought than the naïve way in which our association with our human bodies is assumed.
>
> *Alfred North Whitehead.*

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Notices of Recent Publications

Design For A Brain. By Ross Ashby, 1952. Pp. 254. Chapman and Hall. Price 36s. net.

It is no new idea to regard the observable behaviour of man and animals as the output of some complicated machine, and at present it is particularly fashionable to do so largely because modern calculating machines and servo-mechanisms mimic the human intelligence and capture the popular imagination. But a concept of behaviour which omits, as irrelevant, the entire range of subjective impressions, values, and aspirations naturally has, and always has had, strong opponents. However, the central nervous system is undoubtedly in some sense a machine, and the more precisely we can say what kind of a machine it is, the more clearly shall we be able to evaluate the strength and the weakness of the mechanistic concept.

Dr. Ross Ashby in his "Design for a Brain" has made a valuable contribution in this direction. Adopting a rigidly materialistic attitude he is able to deduce the kind of machine that the brain *must* be and to work out some of its properties. The machine turns out to be a very remarkable one, not at all the sort of thing one is apt to have in mind when one says "I don't see very well how a pure machine could act like this."

Animal behaviour is so dependent upon afferent nerves that Ashby's model must obviously be of the servo type, fitted with signals indicating the actual performance, and with some mechanism which minimizes the divergence between this performance and a pre-set goal. Now in most machines of this type the minimizing mechanism has to be carefully designed and constructed. The really remarkable feature about Ashby's machine is that it builds its own goal-seeking mechanisms from a loose-knit ensemble of elements which constitute its prime structure. This gives it a dynamic self-regulating quality. If for instance one part of the machine were destroyed, the rest would set about rebuilding, from the elements remaining, more or less the same goal-seekers as before, and the function initially lost could be largely recovered. The relations between neuroanatomy, physiological experiments and the concept of organization are not so clear but that a precise treatment which should be capable ultimately of uniting all three deserves consideration.

The book has been very carefully written with every effort to make it clear. Nevertheless it is by no means easy reading, for the author has tried throughout to achieve a mathematical exactness so that the ideas presented may be developed without ambiguity.

The main problem of how the brain-machine learns, i.e. builds its goal-seekers, is shown to be formally analogous to that of the origin of species, and the solution adopted is similar to Darwin's, namely that *selection by survival* when operating upon random variation must in general result in ever-increasing organization and adaptation.

But if the brain is so well adapted to achieve goals it becomes important to know what determines the goals which are to be achieved. The only goals considered in the book are such things as avoiding the setting up of nerve impulses in "pain" fibres. Many will feel that life offers goals of very different quality, goals which depend essentially upon subjective considerations. But they need not on that account disagree with Ashby's design for a brain. For it may well be that the subjective life is concerned with conceiving, evaluating and deciding upon goals and that Ashby has described how the brain builds and uses the machinery which finally achieves them.

W. A. H. R.

Die Psychiatrie der Hirngewülste und die cerebralen Grundlagen psychischer Vorgänge. By HANS WALTHER-BÜEHL, Vienna. 1951. Springer-Verlag. Pp. 226. Price £1 10s.

This monograph presents the findings obtained in the psychiatric examination of 600 cases of brain tumour in the Zürich neurological clinic, and it is to a considerable extent a statistical report. In 70 per cent of the patients there were some mental symptoms; but in the overwhelming majority the symptoms were of a very general kind, such as to indicate the presence of an organic process but not its nature or localization. The principal psychiatric signs took either the form of some degree of clouding of consciousness in acute cases, or in chronic ones the form of an "organic psycho-syndrome" in the sense of E. Bleuler. This syndrome most characteristically includes an impairment of memory, disturbances in the field of association, and alterations of affective response—either apathy or affective lability. Psychiatric symptoms of localizing value were rare; but under this heading the author discusses epileptic fits, including uncinate attacks, aphasia and apraxia, and the so-called frontal syndrome. It is noteworthy that the affective and psychiatric symptoms which have come to be associated with lesions of the temporal lobe, and are now claiming much attention, are hardly remarked on. In 4·5 per cent of the patients there were psychiatric changes of a heterogenous kind: manic, depressive, neurasthenic and even schizophrenic pictures. These could be fully explained by an examination of the family history of the individual patients affected in this way, and of their premorbid personalities; the brain-tumour was considered to have played no more than a precipitating role. Among other general factors that of age was found to be important. The organic psycho-syndrome was of rare occurrence in young patients, but increasingly frequent after the age of 40.

The investigation has been carried out with painstaking care, but its results are disappointing. The reader has the impression that it was begun and conducted on the working hypothesis that mental changes are the reaction of the personality as a whole, and that specific and focal psychiatric symptoms could not be expected. Nevertheless the author is no doubt just in his view that a comprehensive survey of an unselected material is a corrective to the accumulation in the literature of accounts of cases of special interest but infrequent occurrence, in which mental changes of a specific kind have been associated with local lesions.

E. T. S.

Developmental Disorders of Mentation and Cerebral Palsies. By C. E. BENDA. 1952. Grüne and Stratton. New York. Pp. 565 with 102 illustrations. Price £5 2s.

The critical study which has been made in recent years of inborn and developmental disorders of the brain has thrown new light on many aspects of these conditions. More especially have we come to realize that development of the brain continues for many months after birth and that many structural abnormalities which have in the past been considered to date from intra-uterine life are in fact brought about by the stresses of birth. Further complications may arise immediately after birth, such as kernicterus, or as a result of infections such as syphilis and toxoplasmosis. Others may come on more slowly from disorders of metabolism of lipoids, carbohydrates or proteins. It is in this wider sense that the author discusses developmental diseases of mentation, and the great value of his book is the emphasis which is laid on this, essentially preventive, point of view. In metabolic diseases of the brain prevention may appear to be less possible than in cases due to birth trauma; but biochemistry has achieved many seemingly impossible tasks during recent years and it may soon accept the challenge presented by those disorders of

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metabolism which affect the development of the brain. For example the author suggests that phenyl-pyruvic oligophrenia may be partly a tyrosine deficiency. It is possible that this and other developmental metabolic diseases may yield to medical treatment as fully as cretinism and subacute combined degeneration.

The author's interest in the psychology of childhood is shown in the early chapters in which he discusses the assessment of mental development and in Part IV which he devotes to "infantile dementia," "the artistic child" and "childhood schizophrenia." The remainder of the book deals more with the organic basis of mental deficiency, and reflects the author's wide study of pathology. This part contains many mis-statements and omissions of important facts. For example in discussing kernicterus the author makes no mention of the nucleus subthalamicus, changes in which are both the most constant and most clinically significant element in the disease. British workers do not justify the emphasis which he places on mental defect as a sequela of kernicterus, but lay more stress on deafness as a cause both of speech defect and of failure to understand language. In other chapters the reviewer finds statements with which he disagrees on almost every page, but this is inevitable and indeed a healthy sign in any subject on which knowledge is still young. With the author's broader point of view and especially with his emphasis on the importance of birth injuries and infective diseases of early childhood as causes of cerebral palsy we are in full agreement.

This is a monograph rather than a textbook. It makes no attempt to be comprehensive or to give a balanced description of the disorders which it covers, but it gives much more information on many subjects than is contained in larger textbooks. A fuller discussion of the criteria by which the date of onset of cerebral maldevelopments should be judged would have been useful. The absence of all reference to Mongolism is no doubt due to the author's separate monograph on this condition. Of other conditions, such as status marmoratus, the description is slight, but is filled out by illustrative case histories. Altogether this is a very readable and helpful book.

J. G. G.

Diseases of the Nervous System. By W. Russell Brain. Fourth Edition. 1951. Geoffrey Cumberledge, Oxford University Press. Price £2 2s.

Senior students and practitioners should welcome the fourth edition of this well-known textbook, which will not only maintain but enhance its previous reputation.

It has clearly been brought up to date and carefully revised, is well printed on good paper and amply illustrated.

Perhaps the outstanding feature is the lucidity of the author's style and his ability to condense the essentials of a large subject into a relatively short space. Examples of this valuable quality are to be found in the accounts of the disorders of speech and the last chapter of the book on the psychological aspects of neurology. There can be few textbooks which are at the same time so informative and yet so readable.

A. F.